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of the

American Association *of* Petroleum Geologists

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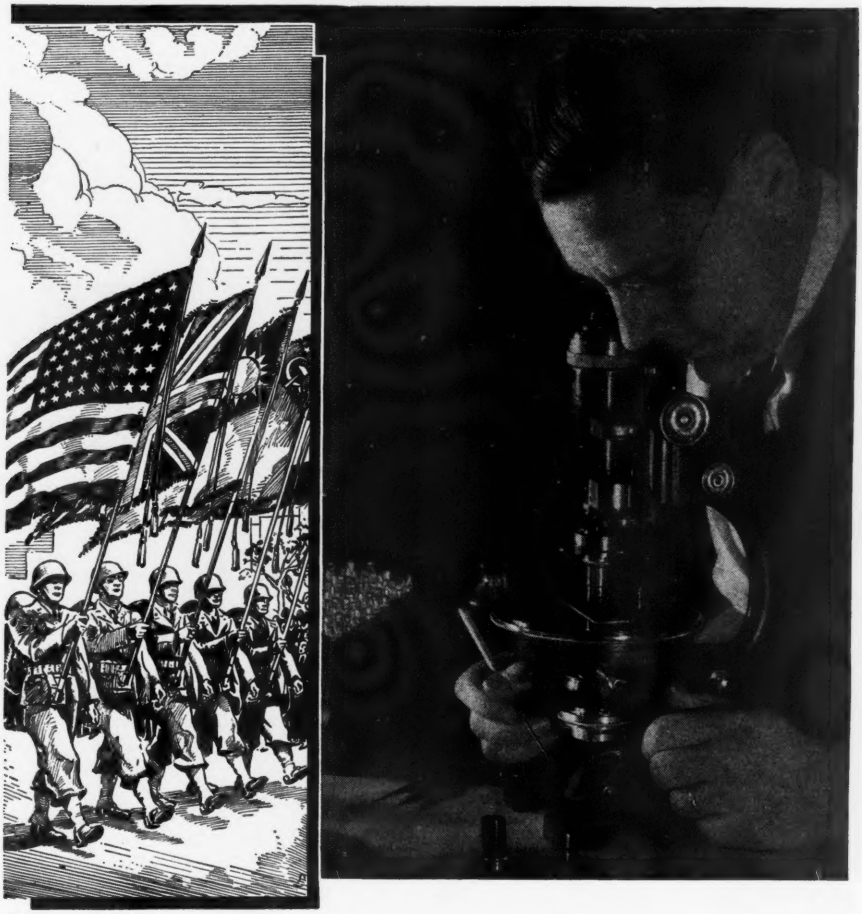

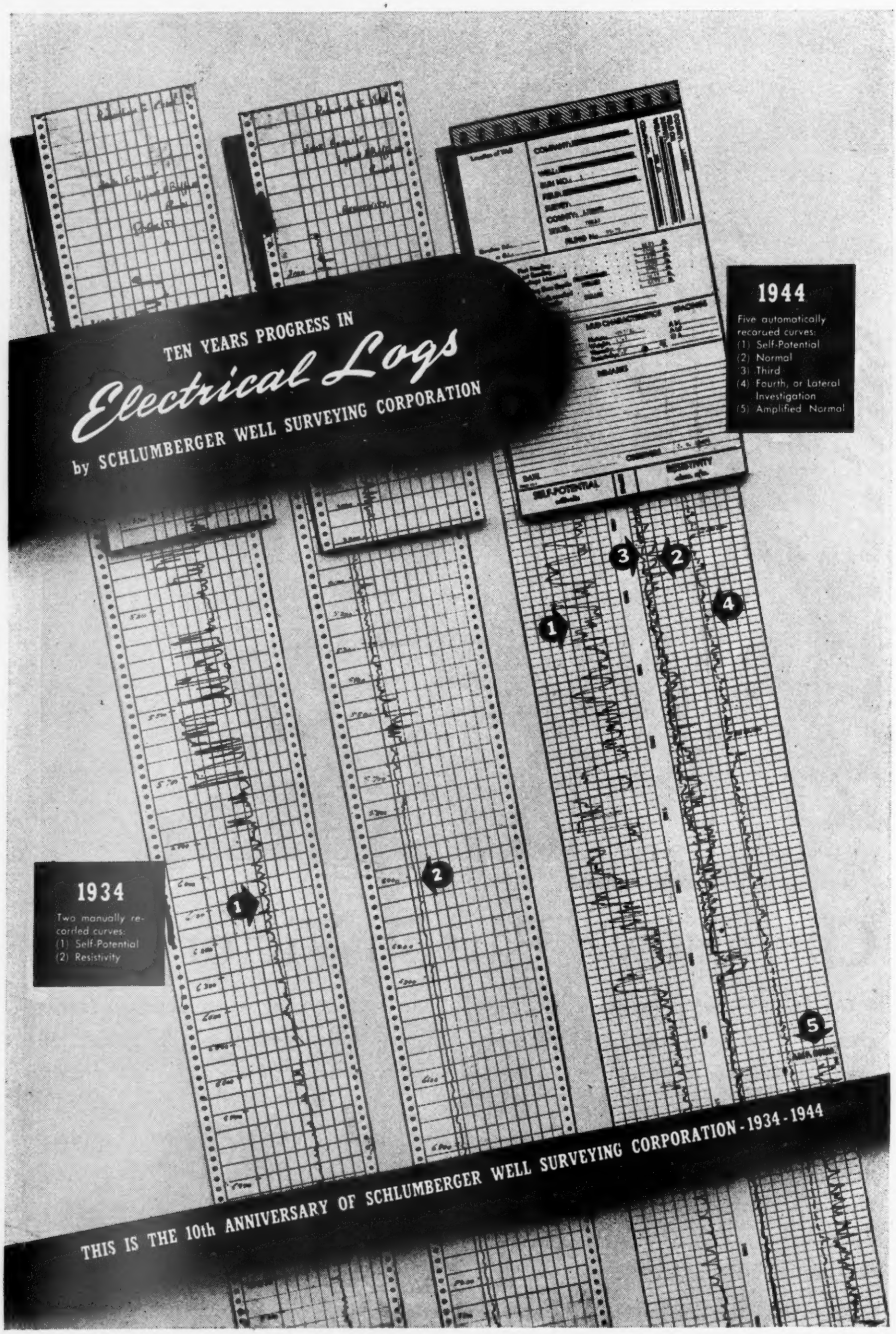

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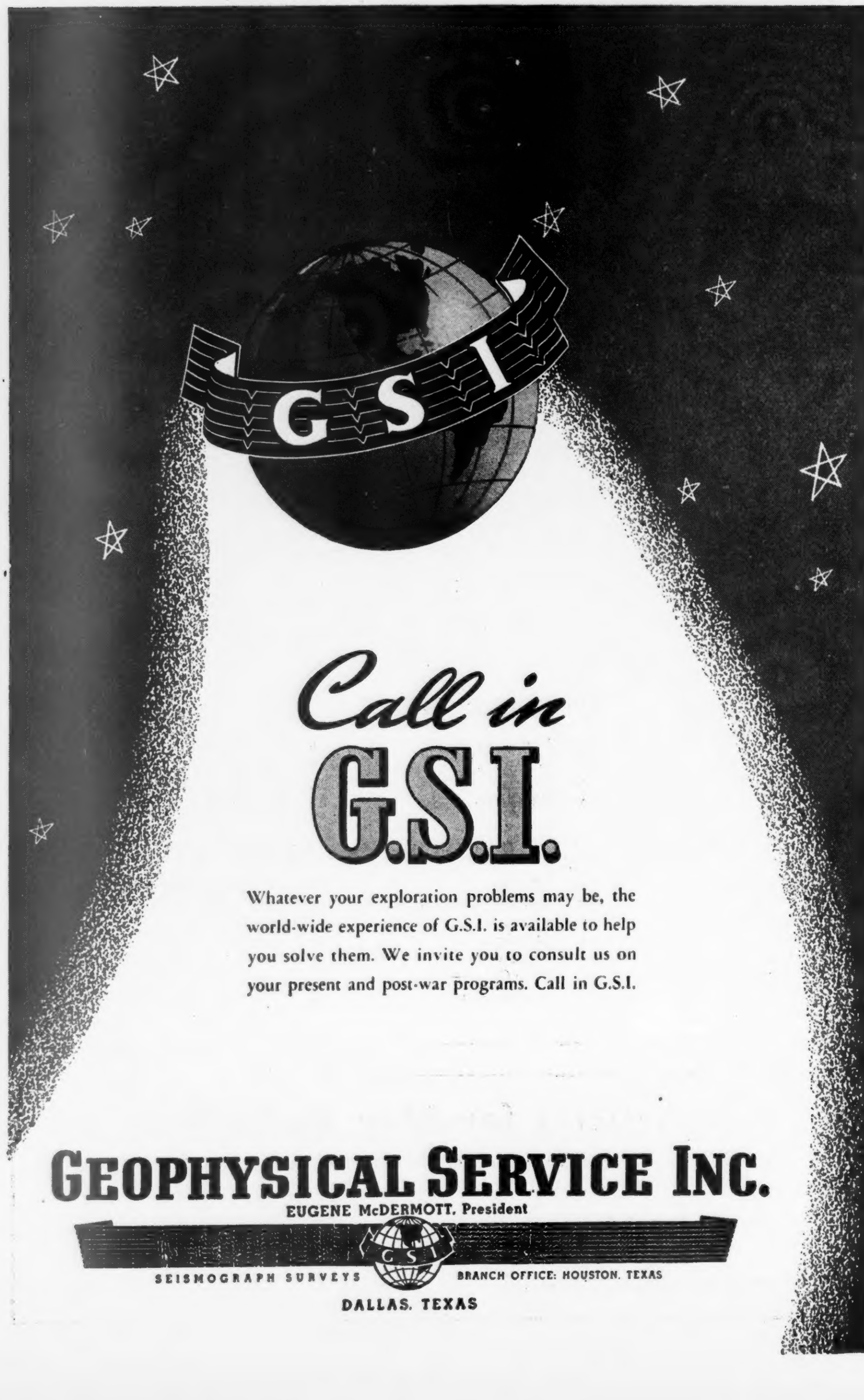
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Volume 28 Number 4

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

APRIL, 1944

CRETACEOUS AND PALEOCENE OF SANTA LUCIA RANGE, CALIFORNIA[1]

NICHOLAS L. TALIAFERRO[2]
Berkeley, California

ABSTRACT

The study of the Cretaceous and Paleocene in the Santa Lucia Range has been of value not only in connection with the sedimentational history of the state but also in deciphering the diastrophic history. Practically all the orogenies that have affected the Coast Ranges since the close of the Jurassic have been strongest in the west, decreasing in effect eastward. Thus, disturbances that resulted in slight disconformities along the west side of the San Joaquin Valley are represented by profound unconformities in the Santa Lucia Range. Relations that in some places are obscure on the east are clear and unmistakable on the west. This is particularly true of the Cretaceous.

Most of the recognized divisions of the Cretaceous are present in the Santa Lucia Range but they are somewhat thinner than in the better known sections in the east part of the Coast Ranges and on the west border of the Great Valley of California.

The Cretaceous of the Santa Lucia Range is divided into three formations separated by profound unconformities. The Lower Cretaceous, the Marmolejo formation, is of rather limited distribution, having been largely removed or covered with later sediments, and occurs only in the south part of the range where it consists of 4,000–5,000 feet of dark shales with minor amounts of sandstone and conglomerate. This rests either disconformably or unconformably on Franciscan-Knoxville rocks with a thin fossiliferous basal conglomerate, except on the east side of the range where there are local, thick, and very coarse breccias largely made up of angular blocks of chert, basalt, diabase, and sandstone derived from the Franciscan. These breccias occur only immediately west of the Las Tablas fault, thinning not far westward away from it, indicating movement, either of folding or faulting, along this zone in the very late Jurassic or early Cretaceous. Local movements of considerable magnitude took place at this time throughout the Coast Ranges. This diastrophism is called the Diablan orogeny by the writer. The meager fauna of the Marmolejo formation indicates that it belongs to the Paskenta stage of the Lower Cretaceous; the Horsetown stage does not appear to be represented.

The Marmolejo formation was strongly deformed and largely removed, as a result of the mid-Cretaceous disturbance, before the deposition of the Upper Cretaceous. Long continued erosion appears to have greatly reduced the region since the earliest Upper Cretaceous sea spread over an area of low relief, as shown by the character of the Jack Creek formation, which consists predominantly of fine-grained detritus, shale and silt, and which rests unconformably on the earlier Mesozoic rocks either without any basal conglomerate or with one only 2 or 3 feet thick. The Jack Creek formation, which is confined to the central and south part of the range, contains a very scanty fauna which has not yet been studied; from evidence in other areas it is believed to represent the Cenomanian and Turonian. The maximum exposed thickness is 2,900 feet but it is ordinarily much thinner because of strong erosion prior to the deposition of the next succeeding Upper Cretaceous unit, the Asuncion. The Jack Creek everywhere rests on Franciscan-Knoxville and Lower Cretaceous rocks; nowhere does it transgress them onto the ancient crystalline complex.

[1] Manuscript received, August 9, 1943.

[2] Chairman, department of geological sciences, University of California.

The Asuncion formation is made up predominantly of coarse detritus, arkose sandstones, and boulder conglomerates and the sea in which it was deposited spread over an area of considerable relief. The Asuncion rests unconformably on the Jack Creek with an angular discordance ranging from a few degrees to 70°. Strong folding, faulting, and, in places, deep erosion took place after the deposition of the Jack Creek before the deposition of the Asuncion. This diastrophism is called the Santa Lucian orogeny by the writer. It uplifted wide areas and caused deep erosion, resulting in the removal of much of the earlier Mesozoic rocks and, in places, exposing the ancient crystalline basement. Although it affected a large area the sea was not completely withdrawn from all of the present Coast Ranges; it decreased in severity eastward and there appear to be areas along the west side of the San Joaquin Valley where deposition was continuous. However, even here there are lenses of coarse boulder conglomerates, containing reworked Cenomanian and Turonian fossils, that are believed to reflect the uplift, or uplifts, caused by the Santa Lucian orogeny.

The Asuncion becomes coarser toward the west and also contains an increasing amount of Franciscan débris in that direction. In the south part of the range it was chiefly derived from the west but in the central and north part of the range there is some evidence that it was derived both from the west and northeast.

The Asuncion, like the earlier Mesozoic rocks of the region, is strongly folded and faulted and commonly stands at high angles. Because of this the total thickness is not known as there are no sections in which both the base and top are exposed. The greatest single section is about 6,000 feet thick; the total original thickness may have been as much as 10,000 feet. Only the upper 1,500–2,500 feet contains determinable fossils. The fauna in the upper part is correlated with the Garzas fauna along the west side of the San Joaquin Valley and the *Glycymeris veatchii* fauna of the Santa Ana Mountains. The range of this fauna is thought to be from the upper part of the Senonian, through the Maestrichtian, into the Danian. The entire Asuncion is believed to be later than the Turonian.

The representative of the Martinez (restricted Martinez, lowermost Eocene) is called the Dip Creek formation. This occurs in only two small remnants about 50 miles apart. In the south part of the range it is 1,320 feet thick and rests with slight unconformity on the Asuncion. The Dip Creek formation is lithologically identical with the Asuncion and the faunas have much in common. The lower conglomerates of the Dip Creek contain abundant débris of the Asuncion and there is a slight angular discordance between them. The movements at the close of the Cretaceous were not as severe or as widespread as those between the Paleocene and lower Miocene.

INTRODUCTION

The Cretaceous of the Santa Lucia Range is represented by three formations, ranging in age from the Lower Cretaceous to a very late stage in the Upper Cretaceous; each is separated by a pronounced unconformity. Because the various Cretaceous and Tertiary diastrophisms were much more severe in the west than in the east part of the Coast Ranges, a study of the Cretaceous of the Santa Lucia Range is important not only in revealing the history of that period in California, but also in contributing to the diastrophic history of the Coast Ranges in general. Slight disconformities on the west side of the San Joaquin Valley are represented by strong unconformities and widespread overlaps in the Santa Lucia Range.

The Cretaceous in general is very sparingly fossiliferous but some beds have yielded moderately large collections. Although these have not been studied in detail sufficient information is available to make reasonably accurate age assignments. Even though it is impossible to present long faunal lists it is believed that a statement of the facts is of value now, especially since it may be several years before it is possible to obtain adequate paleontological assistance in a study of the faunas.

Since the two unconformities between the three cartographic Cretaceous units are definite physical facts, supported by abundant field evidence, the lack of positive information regarding the exact age limits of the formations, although

unfortunate, does not prevent a satisfactory description of the lithologic character, distribution, known fauna, and relationships of the various units to each other and to pre-Cretaceous and Tertiary rocks. Larger collections, and more detailed study of the present collections, may modify the present tentatively assigned age limits but it is not believed that such work would change the broader conclusions regarding conditions of deposition and diastrophic history.

Isolated areas of Cretaceous sediments in which only fragmentary fossils have been found have been assigned to one of the three formations on the basis of lithology and relation to older and younger rocks. The writer is well aware of the danger of such correlations but believes that the lithologic differences between the three are so marked that correlations may be made with reasonable certainty.

The present paper is based on detailed mapping during fifteen summers in the south part of the range and in adjacent areas, on many reconnaissance trips throughout the Coast Ranges, and on the mapping of several quadrangles in the Santa Lucia Range and contiguous areas by graduate students of the University of California.

ACKNOWLEDGMENTS

The writer is greatly indebted to R. E. Turner, C. E. Van Gundy, and C. M. Gilbert, each of whom assisted him for several years in the field, and to more than 250 graduate and undergraduate students of the University of California, who made possible the mapping of nine quadrangles in the Santa Lucia Range. Alex Clark, B. L. Clark, S. W. Muller, and H. G. Schenck have examined a number of the fossil collections. The writer wishes to express his gratitude to the Board of Research of the University of California for generous support of this and other projects.

LOCATION AND EXTENT OF SANTA LUCIA RANGE

On some published maps and on the local topographic sheets of the United States Geological Survey the name Santa Lucia Range is applied to the mountainous area extending southeast from the south side of Monterey Bay, between the Pacific Ocean and the Salinas Valley, and continuing beyond the head waters of the Salinas River to the Cuyama River. South of the Cuyama River the mountainous area is called the San Rafael Range. As has been pointed out previously by the writer,[3] it is illogical to use the Cuyama River as the boundary between the Santa Lucia and San Rafael ranges since there is neither a geologic nor topographic break along this hypothetical boundary. The writer has mapped the Nipomo and Branch Mountain quadrangles, which lie on both sides of the Cuyama River and include parts of both the San Rafael and Santa Lucia ranges, as usually defined. The structure and stratigraphy on both sides of the Cuyama River are identical; folds and faults cross the river and the physiographic history of both sides is the same.

[3] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California." *California State Bur. Mines Bull. 118*, Pt. 2 (1941), p. 119.

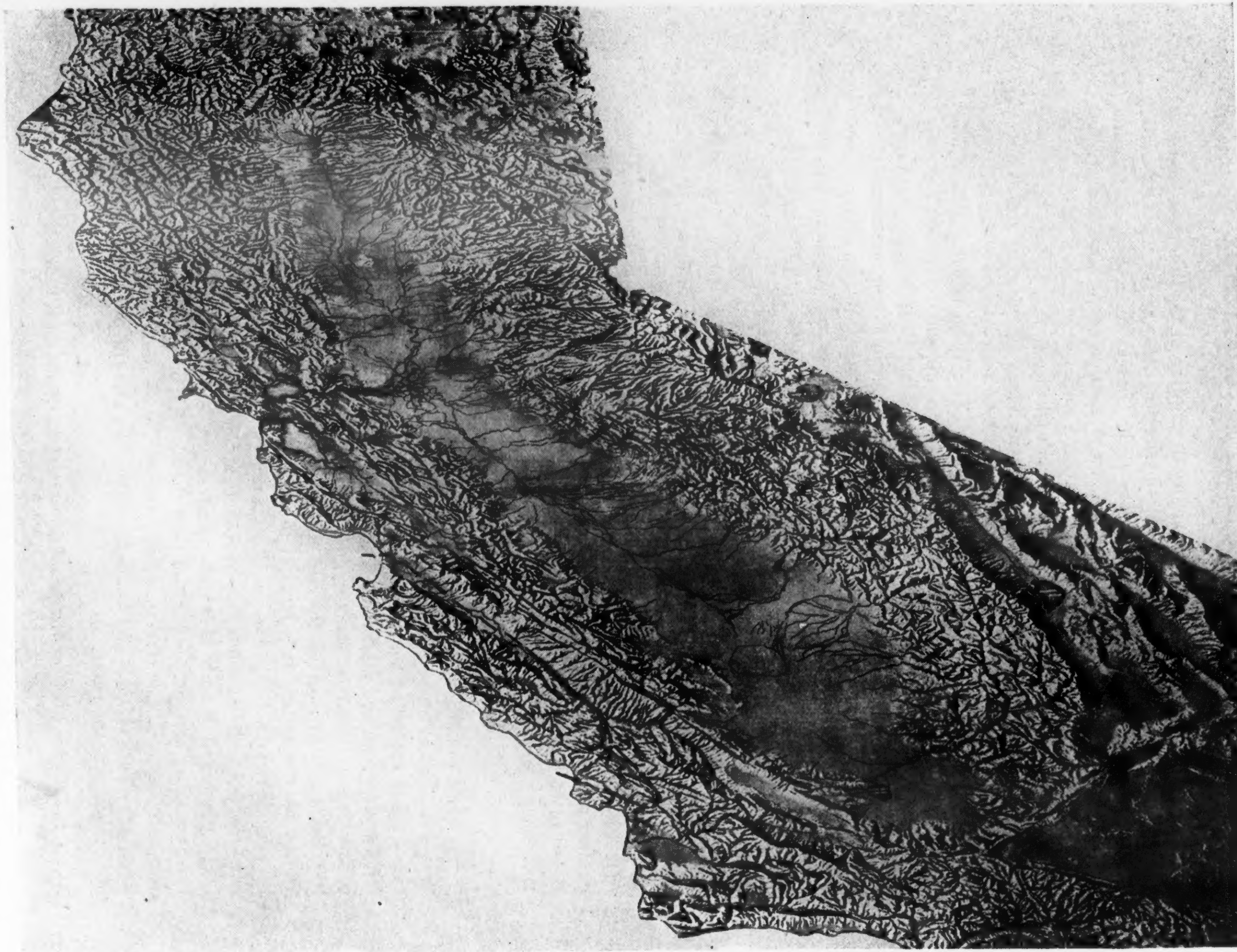

FIG. 1.—Relief map of California, north of Santa Barbara, showing location of Santa Lucia Range and general nature of its relief (oblique view).

Reed[4] stated that the Nacimiento fault forms the east boundary of the south Santa Lucia Range. This also is an unfortunate definition as the broad belt of unrelated faults, called the Nacimiento zone by Reed, crosses the Santa Lucia Range and extends southeast into the San Rafael Mountains.

The north end of the range is clearly defined topographically by the south end of Monterey Bay but the south end is somewhat indefinite both structurally and topographically. Throughout most of its extent the Santa Lucia Range is roughly bounded by inward-dipping marginal thrusts. These die out southeastward, their place being taken by normal faults. If this may be regarded as a legitimate criterion, the range ends at about the latitude of San Luis Obispo. This also corresponds with a marked decrease in elevation and the replacement of the main backbone by several low ridges.

As defined here, the Santa Lucia Range is the mountainous area between the Salinas River and the Pacific Ocean and between Monterey Bay and San Luis Obispo. It has a length of 120 miles and a maximum width of 30 miles. Its south limit is approximately as shown on the Point Conception sheet (North I-10) of the International Map. Figure 1 and Figure 2 show its general location.

Topographically the Santa Lucia Range is made up of several long ridges separated by valleys. However, there is a practically continuous, sharp main crest extending from Carmel, just south of Monterey Bay, to the latitude of San Luis Obispo. This crest roughly parallels the coast and in most places is not more than 7 miles east of it, except in the extreme south part where it is about 15 miles east of the coast. Throughout most of its extent the range rises abruptly from the ocean and a considerable elevation is attained within a short distance. For example, Cone Peak, elevation 5,155 feet, in the southwest part of the Junipero Serra Quadrangle, is only 3 miles from the coast. In the north half of the range, which is higher than the south half, several peaks rise about 4,500 feet; the highest is Junipero Serra Peak, 5,844 feet, about 45 miles southeast of Monterey Bay. In the central part of the range the highest point is Alder Peak, 3,747 feet; southward the elevation of the crest gradually declines to about 3,000 feet in the latitude of San Simeon, although there are a few peaks that rise to more than 3,500 feet. The south end is a little more than 2,500 feet above sea-level.

The range is rugged throughout and is crossed by few roads except in the lower south part. Most of the higher areas are accessible only on foot or horseback.

In the north half of the range the higher regions are chiefly occupied by crystalline schists and plutonics, the Sur series and Santa Lucia intrusives. On the south the crest is in most places made up of Franciscan sedimentary and intrusive rock although Cretaceous sedimentary rocks are present here and there up to elevations of 3,500 feet. The lower south end is made up of Franciscan,

[4] R. D. Reed, *Geology of California*, Amer. Assoc. Petrol. Geol. (1933), p. 12.

FIG. 2.—Generalized topographic map of Santa Lucia Range and adjacent areas. From sheets North J 10 and North I 10, International map, United States Geological Survey.

Cretaceous, and Miocene rocks. In the north part Cretaceous sedimentary rocks are present at elevations of 5,000 feet.

PROGRESS OF GEOLOGIC MAPPING IN SANTA LUCIA RANGE

The entire Santa Lucia Range has been mapped topographically by the United States Geological Survey on a scale of 1 to 62,500 with a contour interval of 25 or 50 feet. Most of it has been mapped geologically although only three quadrangles have been published. During the past 15 years the writer, assisted by students of the University of California, has mapped approximately 3,000 square miles within, and immediately adjacent to, the Santa Lucia Range. The results of this work have not been published.

The following list of quadrangles summarizes the present status of geologic mapping in the Santa Lucia Range. This is shown graphically in Figure 3.

Monterey. Mapped in part. A. C. Lawson, "The Geology of Carmelo Bay," *Univ. California Pub.' Bull. Dept. Geol.*, Vol. 1 (1893), pp. 1–59
Salinas. C. L. Herold. "Geology of the Salinas Quadrangle," *Univ. California unpublished M.A. thesis* (1935)
Point Sur. Parker D. Trask, "Geology of the Point Sur Quadrangle," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 16 (1926), pp. 119–86
Jamesburg. W. M. Fiedler, "Geology of the Jamesburg Quadrangle," *Univ. California unpublished Ph.D. thesis* (1942)
Soledad. L. F. Schombel, "Geology of the Soledad Quadrangle," *ibid., M.A. thesis* (1937)
Metz. Unmapped
Lucia. P. Reiche, "Geology of the Lucia Quadrangle," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 24 (1937), pp. 115–68
Junipero Serra. Northeast corner mapped by N. L. Taliaferro, unpublished
King City. Unmapped
Priest Valley. 1 to 125,000, approximately 1,000 square miles, mapped by N. L. Taliaferro, R. C. Meilenz, and R. M. Phillips, unpublished
Cape San Martin, Bryson, Bradley, San Miguel, Piedras Blancas, San Simeon, Adelaida, Paso Robles. Mapping completed, unpublished. N. L. Taliaferro
San Luis. H. W. Fairbanks, "San Luis, California," *U. S. Geol. Survey Geol. Atlas Folio 101* (1904)
Pozo. South part mapped by N. L. Taliaferro
Nipomo. Mapping completed, 1941, N. L. Taliaferro, unpublished

PRE-CRETACEOUS ROCKS OF SANTA LUCIA RANGE

There are two major groups of rocks older than the Cretaceous in the Santa Lucia Range. The older is the Sur series,[5] made up of quartz mica schists, quartzites, and marble derived from sediments, and amphibole and chlorite schists derived from volcanics and shallow intrusives. These are intruded by the Santa Lucia plutonic rocks, chiefly quartz diorites, but ranging from granites to gabbros. The age of these crystalline schists is not known with certainty since no fossils have been found in them. They have been correlated with the Calaveras of the Sierra Nevada but without factual basis. The writer considers them equivalent to the Abrams and Salmon schists of northern California and the Colebrook schists of southwestern Oregon; these are known to be pre-Silurian in age. He regards the Sur series as either very early Paleozoic or pre-Cambrian.

[5] Parker D. Trask, "Geology of the Point Sur Quadrangle, California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 16 (1926), pp. 127–33.

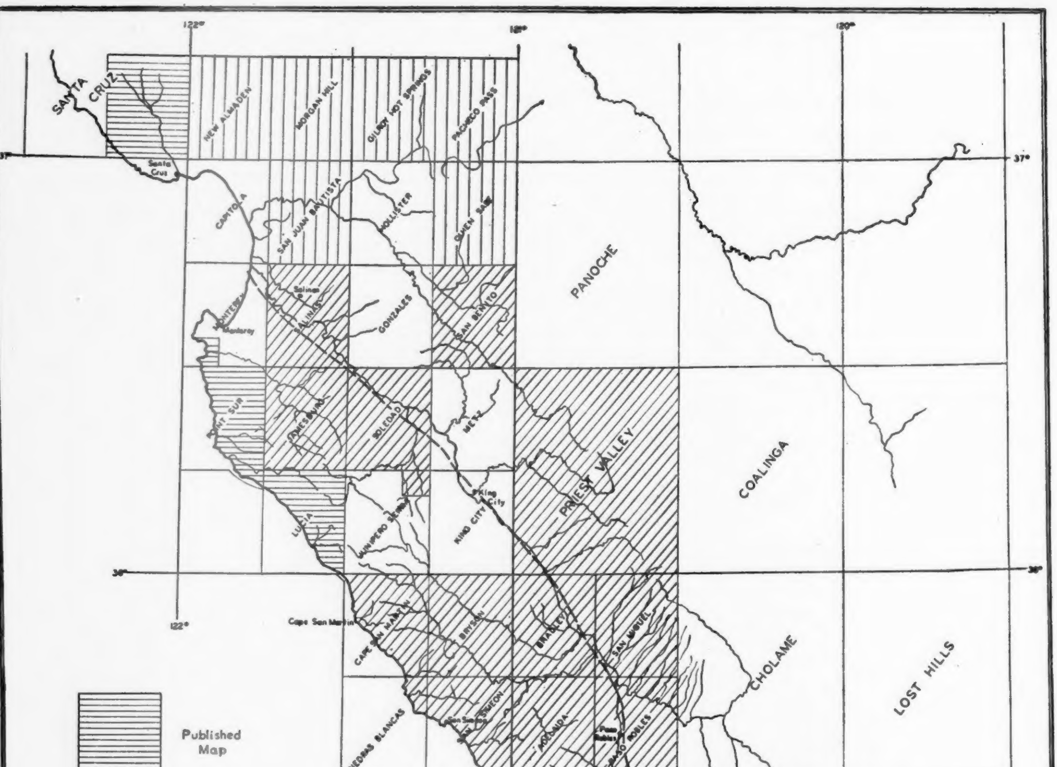

FIG. 3.—Quadrangle map of Santa Lucia Range and adjacent areas, showing progress of geologic mapping and publication.

The Franciscan-Knoxville group is younger than the Sur series and the Santa Lucia intrusives and older than the Lower Cretaceous. Although the Franciscan-Knoxville group is everywhere in fault contact with the older rocks in the Santa Lucia Range, there is no question about their relative ages when the vast difference in the stage of metamorphism is taken into account. Furthermore, the Franciscan-Knoxville sedimentary rocks are largely made up of detritus derived from the crystalline schists and plutonics. Since the Franciscan-Knoxville group has been described previously by the writer[6] it need not be discussed here.

The two older Cretaceous formations (Lower Cretaceous and early Upper Cretaceous) everywhere are associated spatially with the Franciscan-Knoxville group but the third and youngest (late Upper Cretaceous) rests indiscriminately on any of the older rocks; it commonly transgresses the earlier Mesozoic rocks onto the crystalline schists and plutonics. Thus, there was strong diastrophism during the Upper Cretaceous that resulted in uplift and deep erosion, followed by submergence, of the region now represented by the Santa Lucia Range.

DIABLAN OROGENY

At or near the close of the late Upper Jurassic there was a comparatively mild but widespread disturbance that affected a large part of the state in varying degrees. This diastrophism temporarily modified and uplifted parts of the geosyncline in which the Franciscan-Knoxville group was deposited but did not destroy, or even permanently modify, the trough. Although mild in general it was, locally, rather severe and there are areas where the upper phase of the Franciscan-Knoxville group, the "Knoxville shale," was largely or completely removed prior to the deposition of the earliest Lower Cretaceous. In some regions there is a thick conglomerate at the base of the Lower Cretaceous, containing abundant débris of the underlying Franciscan-Knoxville group, but in other areas deposition appears to have been continuous; at least there are places where the basal Lower Cretaceous conglomerates pass into sandstones and then into shales, and the contact is, therefore, in a thick shale section showing no lithologic break. Although it is certain that the fauna of the Franciscan-Knoxville group is late Upper Jurassic and that of the overlying Paskenta stage of the Lower Cretaceous represents an early stage in the Lower Cretaceous, the beds are neither so abundantly fossiliferous nor has the paleontologic work been sufficiently detailed to enable a sharp line to be drawn between the two in the absence of a basal conglomerate. Furthermore, it is by no means certain that the basal conglomerates and the overlaps that appear here and there represent the

[6] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *California State Bur. Mines Bull. 118*, Pt. 2 (1941), pp. 123–27.

———, "Geologic History and Correlation of the Jurassic of Southwestern Oregon and California," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 71–112.

———, "The Franciscan-Knoxville Problem," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 2 (February, 1943), pp. 109–219.

same exact time horizon everywhere. However, there is definite evidence, both in the Santa Lucia Range and throughout the Coast Ranges in general, that strong uplift and, in some places, strong folding took place very close to what is generally regarded, on faunal evidence, as the line between the Upper Jurassic and the Lower Cretaceous. The writer has proposed the name Diablan for the diastrophism that began in the very late Upper Jurassic and probably continued into the early Lower Cretaceous. The sea was not withdrawn completely from the Franciscan-Knoxville trough; local areas were uplifted by folding or faulting, or both and, in some places, several thousand feet of beds were removed. In general the uplift appears to have taken place with only slight folding or tilting, and the attitude of the Lower Cretaceous varies little from that of the underlying beds; in a few places, however, there is marked angular discordance.

Throughout the Santa Lucia Range (and throughout the Coast Ranges south of Tehama County) the Lower Cretaceous rests on the Franciscan-Knoxville group; only in the northern Coast Ranges does it transgress pre-Mesozoic rocks. Although the Diablan orogeny was locally of sufficient magnitude to uplift and remove a considerable prism of rocks prior to the deposition of the Lower Cretaceous it was not severe enough to cause the removal of the Franciscan-Knoxville group over most of the Coast Ranges. It did not destroy the geosyncline in which the Franciscan-Knoxville group was deposited, but it appears to have resulted in islands here and there and to have shifted the main axis of the trough slightly eastward. A more complete account of the Diablan orogeny and its effect in local areas will be given in future papers.

LOWER CRETACEOUS-MARMOLEJO FORMATION (PASKENTA STAGE)

GENERAL STATEMENT

In northern California the Lower Cretaceous has been divided into two groups, the Paskenta and the Horsetown.[7] There is no justification for the use of the term group as a designation of these beds for the following reasons. They are not cartographic units; no one as yet has succeeded in drawing a line between them in the field. There is no break between them, and the Paskenta grades upward into the Horsetown. There is no distinctive lithologic unit at the supposed base of the Horsetown that may be followed. The supposed dividing line between them at one particular locality is not at the same stratigraphic horizon in another locality. Although there are many genera and species that are characteristic of each there are also a number that occur in both. Ordinarily, it is possible to state that a particular fauna is either Paskenta or Horsetown but meager faunas, especially those well above the base of the Lower Cretaceous, certainly are not distinctive. For these reasons the writer feels that the names Paskenta and Horsetown should be used as approximate faunal stages, rather than as group terms.

[7] F. M. Anderson, "Lower Cretaceous Deposits in California and Oregon," *Geol. Soc. America Spec. Paper 16* (1938).

In the Santa Lucia Range all of the fossils found thus far indicate that the beds belong to the lower part of the Paskenta stage, as defined in northern California. Horsetown beds are present on the east in the Diablo Range, and larger collections may show them to be present in the Santa Lucia Range. The absence of Horsetown fossils may be the result of (1) non-deposition over the area, or (2) removal by erosion, chiefly before the deposition of the early Upper Cretaceous. There is no direct evidence favoring either of these hypotheses except that in most places in the Santa Lucia Range both the Lower Cretaceous and the "Knoxville shales" were removed prior to the deposition of the early Upper Cretaceous; it is possible that all of the stratigraphically higher Horsetown beds were removed at this time, leaving only remnants of the lower part of the Lower Cretaceous. On the other hand, the widespread removal of the Lower Cretaceous might be interpreted as evidence favoring non-deposition, the erosion having taken place during the Horsetown stage.

For convenience of reference the name Marmolejo formation is proposed for the Lower Cretaceous of the Santa Lucia Range. One of the widest and most continuous belts of Lower Cretaceous sediments occurs east of Marmolejo Flats in the central part of the San Simeon Quadrangle. The name Toro was given by Fairbanks[8] to the supposedly Lower Cretaceous "Knoxville" in the extreme south part of the Santa Lucia Range. As has been shown by the writer previously the Toro includes sediments, volcanics, and intrusives of Upper Jurassic age as well as Lower Cretaceous sediments that rest unconformably on the Upper Jurassic. The name Toro was forced on Fairbanks by the Committee on Geologic Names of the Survey; it is quite evident that he originally intended to use the name Knoxville in the sense that it was used 40 years ago. Recently the Geological Survey has abandoned the name Toro,[9] stating: "Replaced by Knoxville formation, the local name Toro being considered unnecessary." The Knoxville is still regarded as Lower Cretaceous by the Survey. This subject already has been discussed by the writer[10] and need not be reviewed here except to say that the original Toro includes both the restricted Knoxville (Upper Jurassic) and the Paskenta stage of the Lower Cretaceous; the two are separated by an unconformity. The Knoxville part of the Toro contains pillow basalts and is intruded by basic and ultrabasic igneous rocks; the Lower Cretaceous part of the Toro contains no igneous material except as débris in the conglomerates. The writer hesitates to introduce a new formational name but in order to avoid confusion and the use of cumbersome terms, such as "Paskenta stage of the Lower Cretaceous" or "lower part of the Shasta group," the name Marmolejo formation is proposed for the Lower Cretaceous of the Santa Lucia Range.

[8] H. W. Fairbanks, "San Luis, California," *U. S. Geol. Survey Geol. Atlas Folio 101* (1904).

[9] M. Grace Wilmarth, "Lexicon of Geologic Names of the United States," *U. S. Geol. Survey Bull. 896* (1938), p. 2169.

[10] N. L. Taliaferro, "The Franciscan-Knoxville Problem," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 2 (February, 1943), pp. 109–219.

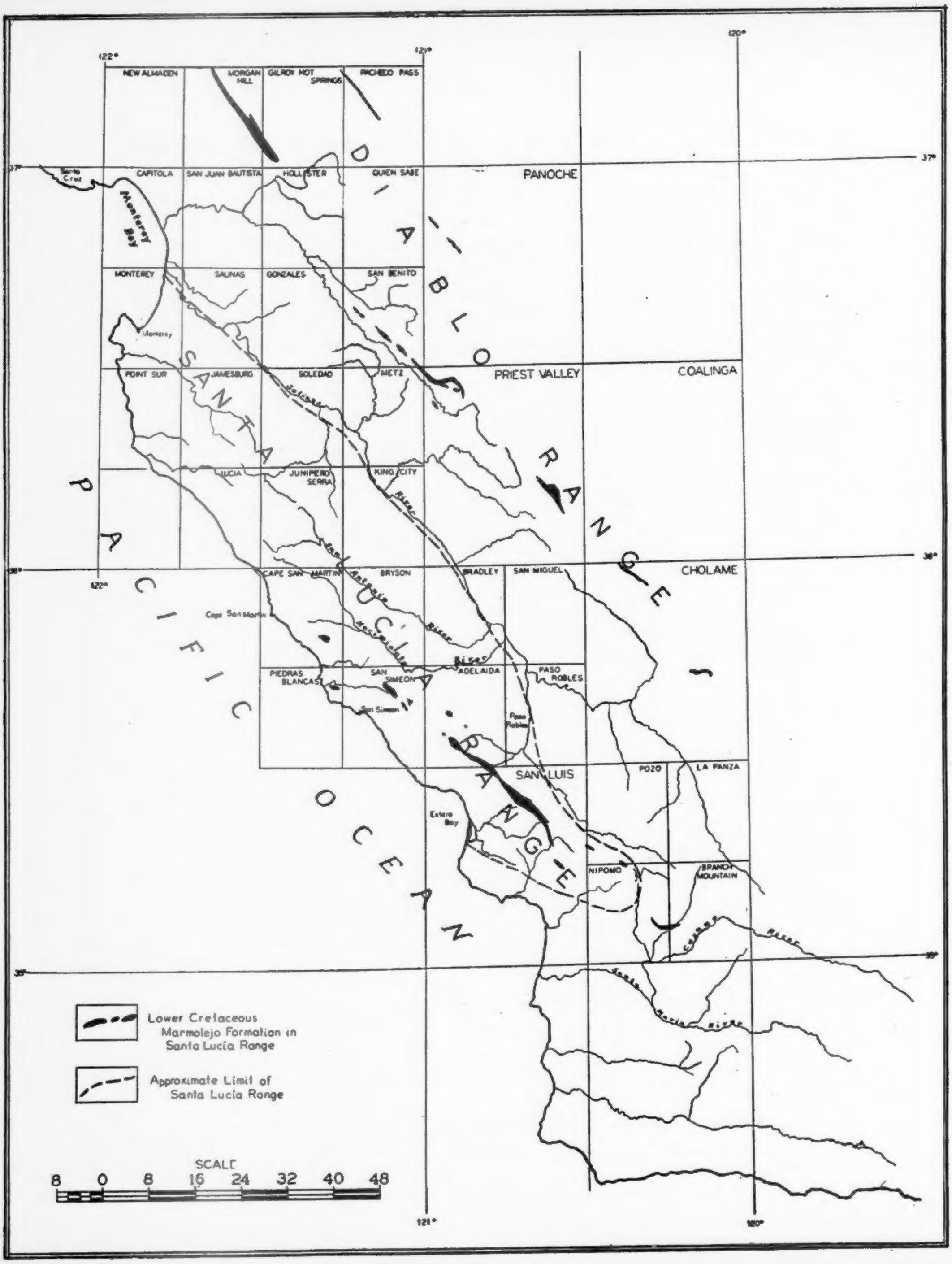

FIG. 4.—Map showing distribution of Marmolejo formation (Paskenta stage of Lower Cretaceous) in Santa Lucia Range and distribution of Lower Cretaceous in general from latitude of Monterey Bay to Cuyama River (south boundary of San Luis Obispo County).

DISTRIBUTION

Lower Cretaceous sediments are rather widely distributed in the south half of the Santa Lucia Range as small discontinuous areas preserved, in most places, by downfolding or faulting. The distribution of the Marmolejo formation in the Santa Lucia Range and the actual outcrops of the Lower Cretaceous in adjacent areas are shown on Figure 4. All of the occurrences of the Lower Cretaceous shown are closely associated in space with the Franciscan-Knoxville group, indicating that the erosion caused by the Diablan orogeny was not sufficiently severe to remove all of the Upper Jurassic. In the area shown the Lower Cretaceous nowhere overlaps the Franciscan-Knoxville group onto the older crystalline rocks.

Although in comparatively small scattered areas, Lower Cretaceous sediments are rather widely distributed throughout the Coast Ranges from the central valley region to the Pacific Ocean. From the general pattern shown on Figure 4 it might be thought that these sediments were deposited in separate troughs and that much of the Coast Ranges was above sea-level during the Lower Cretaceous. However, this apparent pattern is controlled by structure rather than original distribution. The two lines of outcrop on the flanks of the Diablo Range represent remnants preserved in belts that are both topographically and structurally lower than the uparched central part of the range. The belt through the south part of the Santa Lucia Range is essentially synclinal, although in many places complicated by downfaulting, or rather by the thrusting of the Franciscan over the Lower Cretaceous.

The lithologic uniformity and the great similarity of the fauna in practically all of the occurrences of the Lower Cretaceous, not only in the Santa Lucia Range but throughout the Coast Ranges of California and Oregon, are opposed to the concept of deposition in separate basins. Practically everywhere the Lower Cretaceous is made up of dark clay shales, dark sandy shales, hard silty sandstones, and light conglomerates. It is believed that the wide distribution and the lithologic and faunal similarity indicate that the Lower Cretaceous was deposited in a sea that spread across the Coast Ranges, from the central part of the present Great Valley (Sacramento and San Joaquin valleys). As there were two very strong orogenies in the Cretaceous, after the deposition of the Lower Cretaceous, and several in the Tertiary and at least one in the Pleistocene, it is not surprising that the Lower Cretaceous was stripped from most of the region; considering the severity of several of the diastrophisms it is surprising that the Lower Cretaceous is preserved in so many places.

FOLDING, FAULTING, AND ALTERATION OF MARMOLEJO FORMATION

Throughout its extent in the Santa Lucia Range the Marmolejo formation is strongly folded and faulted, its deformation being comparable with that of the underlying Franciscan-Knoxville group. However, it is younger than the basic and ultrabasic intrusives, so common in the older rocks, and has not been altered by local contact action or the general increase in temperature brought about by

igneous activity. Furthermore, because of the absence of contemporaneous volcanics and cherts, it is not as heterogeneous an assemblage; therefore, the sedimentary rocks are not, as a rule, so greatly sheared and distorted by crushing against the more rigid masses, during subsequent diastrophisms. Nevertheless, it has been severely deformed, the shales are hard and in places somewhat slaty and the sandstones and conglomerates are thoroughly indurated. Since the Marmolejo sediments are ordinarily preserved at present in synclines, none of the areas extends to great depth below sea-level. However, it has been buried, in some places, to a depth of at least 10,000 feet; hence, is commonly highly indurated.

Most of the contacts are faults and it is only here and there that its original relationship to older and younger beds is clearly shown. However, these original relationships have been observed in a sufficient number of widely separated localities to obtain a reasonably accurate picture of its former extent, the conditions of deposition, and subsequent history. Because, however, of the intricate folding and faulting it has been impossible satisfactorily to estimate its thickness.

Not only in structure and areal distribution but also in its lithologic character and degree of alteration the Marmolejo formation bears a closer relation to the underlying Franciscan-Knoxville group than to the overlying Upper Cretaceous formations.

The only igneous intrusions in the Marmolejo formation are the dikes and plugs that acted as feeders for the Miocene volcanics; these have only slightly baked and altered the shales a few feet from the contacts. An excellent example occurs at the south end of Black Mountain, Adelaida Quadrangle, where a few olivine basalt dikes cut dark Marmolejo shales, baking and slightly reddening them along the contact. Greater alteration may have taken place along some of the larger Miocene rhyolite necks, quartz porphyry plugs, and analcite diabase feeders but all such contacts either have been removed by erosion or buried beneath later sediments.

Serpentines occur in the midst of the Lower Cretaceous but they are cold injections along faults or faulted anticlines. The best example of a cold injection of serpentine occurs along the northeast side of Black Mountain, Adelaida Quadrangle, along an overturned, thrust faulted anticline in the Marmolejo formation. Here serpentine has been squeezed upward along the faulted crest of an anticline overturned toward the southwest. The serpentine has carried up blocks of Franciscan chert, basalt, and sandstone. The same belt of serpentine, with included blocks of Franciscan rocks, rises northeastward along the same thrust into Miocene sedimentary and volcanic rocks. It is clearly a cold injection or piercement that has been squeezed upward into both the Lower Cretaceous and the Miocene along a northeastward-dipping thrust fault. On the southeast there are several small areas of intensely sheared serpentine squeezed into the Marmolejo formation along the same broken, overturned anticline. These relations are shown in Figure 8.

LITHOLOGIC CHARACTER

Although the lithologic character of the great bulk of the Marmolejo formation, as well as that of the Lower Cretaceous of the Coast Ranges as a whole, is everywhere practically identical, there are certain local variations, particularly in the basal beds, that may be related to their proximity to elevations brought about by the Diablan orogeny.

Nearly everywhere the Lower Cretaceous consists of a monotonous sequence of dark clay shales or dark sandy shales, with thin intercalations of hard silty sandstone; shale ordinarily predominates. There are sandstone lenses up to 100 feet in thickness and there are some lenses of light conglomerate. Very thin beds and small lenses of dark impure sandy or shaly limestone occur in the shales but they are not as abundant as in the underlying Knoxville. There is no important lithologic variation in the Marmolejo formation from one locality to another except in the basal beds, which vary widely in thickness and in the type and angularity of débris.

Nearly everywhere there is a conglomerate at the base of the Marmolejo formation, which rests disconformably or unconformably on either the Knoxville shale phase of the Franciscan-Knoxville group or on a lower typical "Franciscan" assemblage of sandstones, cherts, basalts, and diabase. In some places the uplift resulting from the Diablan orogeny was of sufficient magnitude to cause the removal of all of the Knoxville shale and a little of the Franciscan. Because of subsequent erosion and burial beneath later sediments little can be said regarding the full extent of the Diablan orogeny in the Santa Lucia Range. However, at least 2,000 feet of beds were removed in a local zone through the central part of the Adelaida Quadrangle. West of this zone little erosion took place and the Marmolejo formation rests on the Knoxville shales.

Ordinarily the basal beds of the Lower Cretaceous consist of 5–50 feet of alternating lenses of hard conglomerates and sandstones. Cobbles up to 6 inches in diameter are present but the average diameter of most of the pebbles is less than an inch. With a few exceptions, the pebbles and cobbles in the basal conglomerates are small and well rounded and are of rather resistant rock types. Pre-Franciscan pebbles include various types of quartz and feldspar porphyries, red, gray, and white quartzites, black recrystallized cherts, recrystallized flow-banded rhyolites, schists, quartz, aplite, pegmatite, and granodiorite. Franciscan-Knoxville débris consists of red, green, and white radiolarian chert, basalt, diabase, gabbro, serpentine, and sandstone. Angular and partly rounded fragments of Knoxville limestone and shale are commonly present. The matrix of the conglomerate and the finer-grained interbeds are of sandstone that is somewhat coarser than the ordinary intercalations in the shales. This type of basal conglomerate rests unconformably on the Franciscan in several places on the east flank of a strongly faulted and folded syncline in the south-central part of the Adelaida Quadrangle. (The most accessible locality is near the Josephine School both east and west of the York Mountain road.) Because of strong faulting the

normal relations between the Franciscan and Marmolejo are exposed only here and there on the east side of this synclinal belt of Marmolejo, but where the faulting is wholly within one or the other the relationship is clear; this occurs in the south part of the Adelaida and the north part of the San Luis quadrangles. The west side of the syncline ordinarily is either faulted or is covered by Miocene sedimentary and volcanic rocks but at one place in the Adelaida Quadrangle (Cienega Creek) and at several places in the San Luis Quadrangle the basal conglomerate of the Marmolejo rests on Knoxville shales. As a result of the Diablan orogeny the upper shale phase of the Franciscan-Knoxville group, the Knoxville shales, was completely removed from the region on the east side of the syncline.

On the west side of Marmolejo Creek and Marmolejo Flats the Marmolejo formation rests on Knoxville shales without any apparent unconformity. However, the thin (10–30 feet) basal conglomerate contains débris of both the Knoxville and the Franciscan as well as pebbles of pre-Franciscan rocks.

The basal conglomerate, made up of well rounded pebbles, is commonly fossiliferous; individuals are abundant but species are few, being limited to a few species of aucellas and belemnites. Ammonites are present, but fragmentary and too poorly preserved even for generic determination.

A very different type of basal conglomerate has been found in two places in the Adelaida Quadrangle. Both of these occurrences are on or near the Las Tablas thrust zone, a complex zone of faulting along which movement occurred in the Pliocene, Eocene, and Upper Cretaceous.

In the west-central part of the Adelaida Quadrangle, immediately west of Las Tablas Creek and a mile northwest of the Klau quicksilver mine, and also 5 miles southeast in the south-central part of the quadrangle there are coarse breccias at the base of the Marmolejo formation. At the locality northwest of the Klau mine Lower Cretaceous sediments are preserved in a sharp east-west trending, pre-Upper Cretaceous syncline immediately west of the Las Tablas thrust zone; the area is about a mile long and ½ mile wide. Here the Lower Cretaceous rests directly on the Franciscan which is locally made up of pillow basalts, cherts, sandstone, and diabase, all present as angular blocks in the basal Lower Cretaceous breccias. The breccias are present at the base of the Marmolejo all about the syncline but they are much coarser and thicker on the east than on the west, indicating derivation from a near-by east source. The only two occurrences of coarse breccias in the Lower Cretaceous of the Santa Lucia Range occur along the Las Tablas fault zone. The breccias indicate strong local uplift, either folding or faulting; if the latter, the Las Tablas zone dates back to the Diablan orogeny. If actual movement took place along this zone in the late Upper Jurassic it is the earliest evidence of faulting observed by the writer in the Coast Ranges.

Along the east end of the syncline the basal 400 feet of the Marmolejo consists of coarse breccias with thin interbeds of coarse pebbly sandstone and dark sandy shale. These pass upward into dark silty shales and thin sandstones characteristic of the Lower Cretaceous throughout the state.

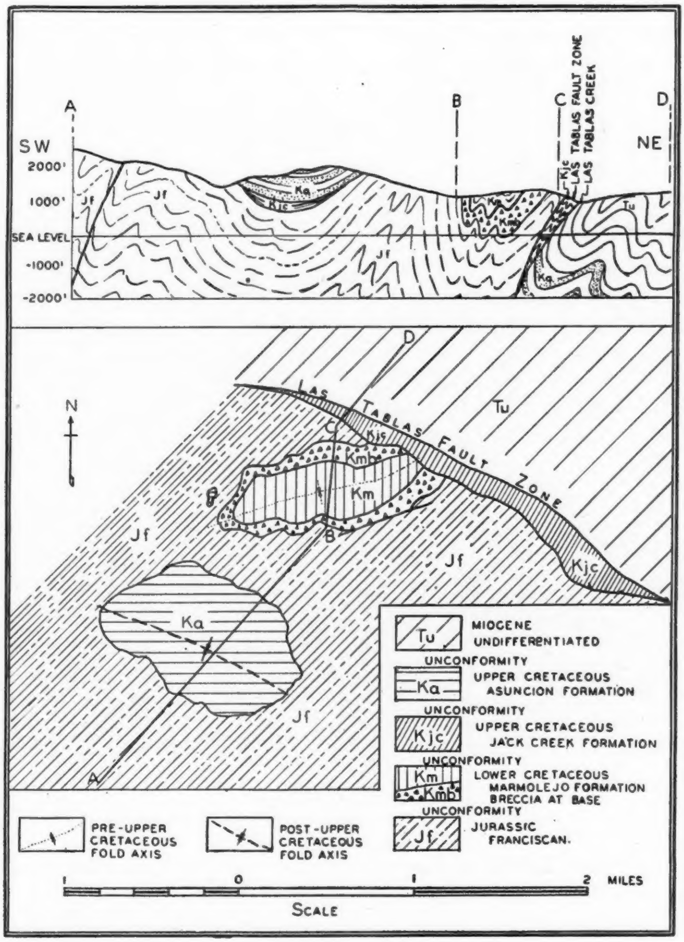

FIG. 5.—Map and cross sections showing relations of Marmolejo breccia in vicinity of Las Tablas fault zone. Adelaida Quadrangle.

In the northeast part of the syncline large angular blocks of Franciscan rocks are present in the breccias, which are exceptionally well exposed along a tributary to Las Tablas Creek. Blocks of basalt with the following dimensions were noted: 9 by 6 by 5 feet, 10 by 4 by 3 feet, 11 by 6 by 4 feet. One block of basalt contains 16 visible pillows on one surface. One almost square block of chert 3 by 3 feet is embedded in the breccia in the bottom of the creek. Smaller blocks of gabbro, sandstone, and Knoxville limestone are abundant. Locally, the Franciscan is

predominantly of basalt flows, commonly with pillow structure; this probably accounts for the size and abundance of the basalt blocks in the breccia.

Well rounded pebbles of pre-Franciscan porphyries, quartzites, and aplites as well as Franciscan cherts, basalts, and sandstone occur scattered through, and as well defined lenses in, the breccias and interbedded sandstones. These lenses are in every way similar to the normal type of basal conglomerate pre-

FIG. 6.—Breccia near base of Marmolejo formation (Lower Cretaceous). Adelaida Quadrangle. 18-inch hammer rests on large block of radiolarian chert.

viously described. However, the normal type was largely masked by the more rapidly accumulating coarser débris.

It appears as though the Lower Cretaceous sea spread eastward to the base of a recently uplifted sea cliff, raised either by folding or faulting, along the ancestral Las Tablas fault zone. Wave attack caused rapid undercutting that resulted in local slides of angular débris into the encroaching sea. At the same time the typical gravelly, sandy, and silty detritus was being washed in, largely from the west.

The local relations of the breccias are shown in Figure 5; Figure 6 illustrates the breccias.

Aside from the breccias just described the lithologic character of the Lower Cretaceous is remarkably uniform. The shales are generally silty and commonly

show the typical shaly spheroidal jointing that permits them to be peeled somewhat like an onion. This phenomenon is not confined to the Lower Cretaceous but is present in almost all similar shales; it simply represents slight contraction toward dispersed centers caused by partial dehydration of the original colloidal clays. On fresh surfaces they are dark gray to black, weathering to dark brown to red-brown on oxidation of the iron. Where erosion is moderately active the gulch and canyon walls cut into the shales have a dark, somber appearance; surfaces above the cuts are covered with dark red-brown soil that, as a rule, supports a meager plant growth.

The limestones that here and there occur as small lenses and thin layers in the shales are very impure and silty; they are dark-colored and ferruginous, weathering to dark brown and ultimately, with the solution of most of the calcium carbonate, to a mass of earthy yellow limonite. The impure limestones are rarely fossiliferous.

The thin interbedded sandstones are similar in most respects to those in the upper part of the Franciscan-Knoxville group; they differ chiefly from the bulk of the lower Franciscan sandstones in the proportion of clayey material and degree of weathering of the constituents. As has been shown previously by Davis[11] and by the writer[12] the Franciscan sandstones are characterized by an abundance of remarkably fresh and angular plagioclase and orthoclase feldspar. The Knoxville and Lower Cretaceous sandstones are likewise characterized by an abundance of angular feldspar but in them it is slightly more altered (by weathering prior to deposition) than in the typical Franciscan sandstones. Furthermore, the Lower Cretaceous sandstones are, in general, finer-grained and contain a greater proportion of clayey material than those in the lower part of the Franciscan. The coarse detritus making up the Franciscan was derived in large part from a high rugged land mass west of the present coast under conditions of predominant mechanical disintegration. As the land mass was worn down, chemical weathering increased in importance, resulting in a greater proportion of clayey material and greater alteration of the feldspars in the upper part of the Franciscan-Knoxville group; lowering of this western land mass continued into the Lower Cretaceous.

The Marmolejo sandstones are thoroughly indurated, being cemented with silica, calcium carbonate, and by a partial recrystallization of the fine clayey matrix. They are almost as difficult to break down as are the Franciscan sandstones. Mechanical analyses mean nothing as it is impossible to obtain a clean separation of the grains. The few partial mineral analyses that have been made indicate the same general types of minerals that are present in the Franciscan sandstones.

[11] E. F. Davis, "The Franciscan Sandstone," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 11, No. 1 (1918).

[12] N. L. Taliaferro, "The Franciscan-Knoxville Problem," *op. cit.*

The cross-bedding in the sandstones, the silty nature of the shales, the presence of thin lenses of conglomerate, and the comparative abundance of aucellas at many horizons indicate that the Marmolejo was deposited in shallow water in a slowly sinking basin, bordered, except locally, by a comparatively low land mass. As the Marmolejo occurs only in scattered remnants it is difficult to obtain positive evidence of the direction of the land mass from which the detritus was derived except in the case of the local breccias along the Las Tablas fault zone. Although these breccias clearly were derived from the east it is believed that the great bulk of the sediments had a western source. This is based on the fact that the impure limestones are somewhat more abundant on the east and that the sandstones are more abundant and slightly coarser toward the west and southwest. Furthermore the Lower Cretaceous in the Santa Lucia Range appears to contain a slightly greater proportion of thin interbedded sandstones than in the Diablo Range on the east.

Fragmentary carbonized plant remains are very abundant in the Marmolejo but well defined leaf imprints have not been found. The condition of the plant remains indicates that they had been transported for some distance and were rather thoroughly macerated before incorporation in the sediments. The abundance of carbonized plant remains indicates that the land from which the sediments were derived was well wooded. Plant remains are even more abundant in the Upper Cretaceous.

RELATION OF MARMOLEJO FORMATION TO OLDER AND YOUNGER ROCKS

Because of many severe diastrophisms to which the region has been subjected since the Lower Cretaceous most of the contacts of the Marmolejo formation are faults. As previously stated the Marmolejo everywhere rests on the Franciscan-Knoxville rocks and nowhere overlaps the old crystalline rocks, Sur schists, or Santa Lucia plutonics.

The next succeeding Cretaceous formation, the Jack Creek, of lower Upper Cretaceous age, has not been found in any but faulted contact with the Marmolejo. As shown on restored cross sections, of which Figure 8 is an example, the Jack Creek must have been deposited across the upturned edges of both the Franciscan-Knoxville and the Marmolejo.

The Asuncion (late Upper Cretaceous) formation also is ordinarily in fault contact with the Marmolejo but in several places in the San Simeon, Adelaida, and San Luis quadrangles, Asuncion sandstones and conglomerates rest on the Marmolejo with marked angular discordance. However, even where the Asuncion rests on the Marmolejo it does not contain any noticeable amount of débris of the latter, indicating that the distribution of the Marmolejo was comparatively limited, even during the late Upper Cretaceous, and had been largely, if not completely, stripped from the highlands from which the Asuncion was derived.

AGE AND THICKNESS

Although fossils are rather abundant in the Marmolejo formation, only a few genera and species are represented. The most abundant species are *Aucella crassicolis* Keyserling, *A. crassa* Pavlow, *A. inflata* Toula, *A. lahuseni* Pavlow, and *Acroteuthis marcarthyensis* Anderson.[13] As stated previously by the writer,[14] the robust, thick-shelled forms, *Aucella crassicolis* and *A. crassa*, and the smaller, narrower, less inflated form usually called *A. lahuseni*, are not confined to the lower beds of the Paskenta but range downward into the upper beds of the Knoxville (Upper Jurassic), where they are associated with the typical Tithonian fossil *A. piochii* Gabb. However, these forms are more abundant in the Lower Cretaceous, where they are not associated with *A. piochii*. They do not extend into the Horsetown. The belemnite (*Acroteuthis marcarthyensis*) found in the Marmolejo does not extend downward into the Knoxville but it, or similar forms, occur in the Horsetown. Identical aucellas and belemnites are found in the Nipomo Quadrangle at the south tip of the Santa Lucia Range, associated with *Turbo paskentaensis* Stanton and in the same position in the Diablo Range 40 miles northeast associated with the typical Lower Cretaceous ammonite, *Neocomites neocomiensis* d'Orbigny. There can be no doubt that the fossils found in the Marmolejo formation indicate that it represents a comparatively low stage in the Lower Cretaceous.

The Marmolejo formation has been so strongly folded and faulted that it is impossible to make an unqualified statement regarding its thickness. The thickness of the beds at the type section east of Marmolejo flats is approximately 5,000 feet, unless repeated by faulting. Here the Marmolejo rests on Knoxville shales and the base is exposed; however, the top is not exposed as the beds are cut off on the east by a profound fault that, locally, follows the crest of the Santa Lucia Range. The outcrop width is approximately 5,200 feet, the eastern faulted contact is 1,000 feet higher than the base, and the average dip is 60°. Hence, the exposed part is approximately 4,900 feet thick.

MID-CRETACEOUS DISTURBANCE

The next youngest Cretaceous formation, the Jack Creek, of Upper Cretaceous age, was deposited after the removal of a large part of the Marmolejo formation and after the entire region had been reduced to an area of low relief. Hence, a considerable amount of uplift and deep erosion must have taken place between the two. The Jack Creek formation is known to be Upper Cretaceous but its exact position is not known; hence, the disturbance can not be dated more closely than post-Paskenta and earlier than some unknown stage in the lower

[13] F. M. Anderson, "Lower Cretaceous Deposits in California and Oregon," *Geol. Soc. America Spec. Paper 16* (1938), p. 230, Pl. 83.

[14] N. L. Taliaferro, "Geologic History and Correlation of the Jurassic of Southwestern Oregon and California," *ibid.*, Vol. 53 (1942), pp. 71–112.

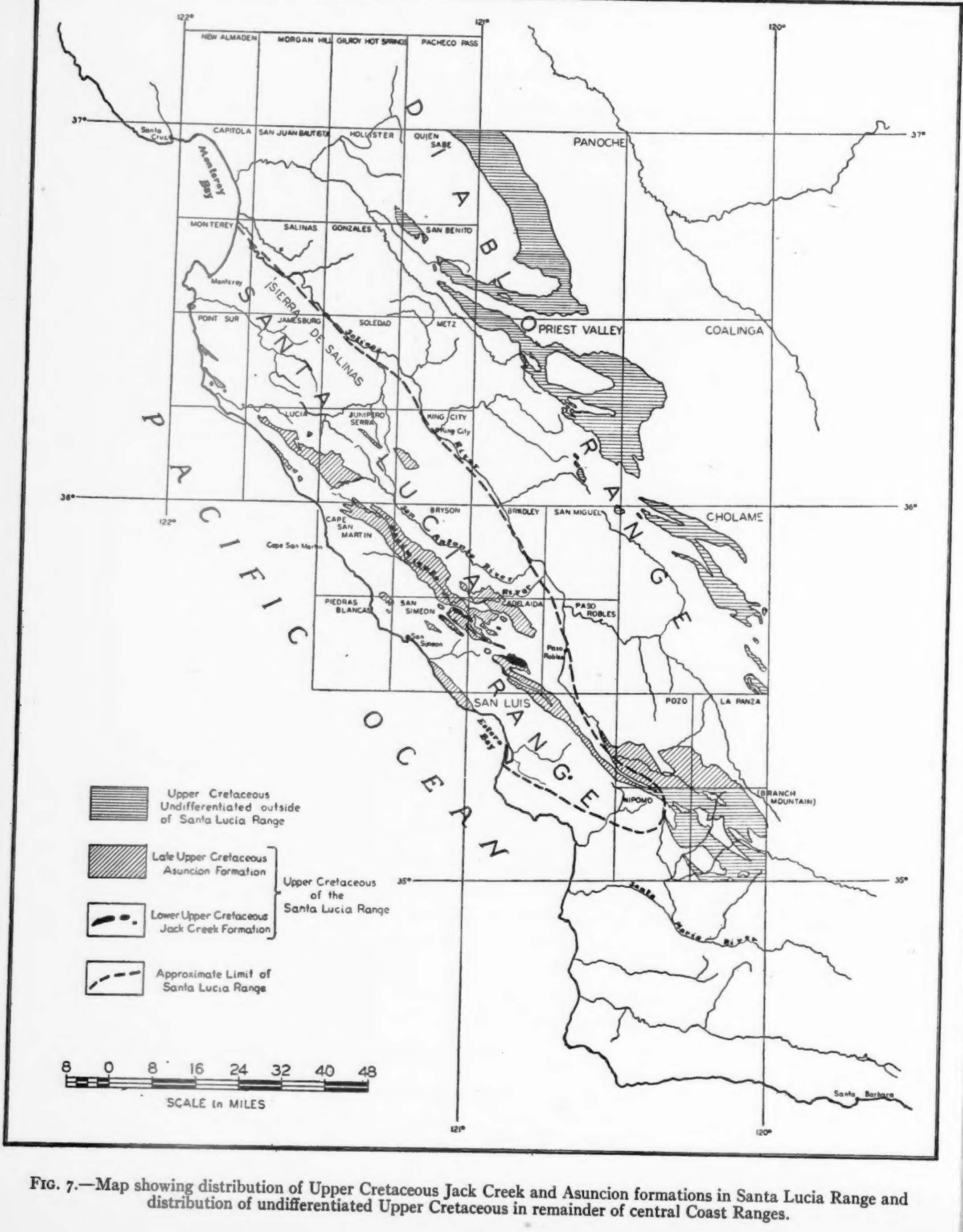

FIG. 7.—Map showing distribution of Upper Cretaceous Jack Creek and Asuncion formations in Santa Lucia Range and distribution of undifferentiated Upper Cretaceous in remainder of central Coast Ranges.

Upper Cretaceous. However, Upper Cretaceous rocks rest with slight angular discordance on Horsetown beds in the northern Coast Ranges and with marked unconformity on Paskenta beds in the Diablo Range and they are known to be at least as old as the Cenomanian, and possibly as old as the late Albian. Like all succeeding diastrophisms the mid-Cretaceous disturbance was greater in the Santa Lucia Range than farther east, resulting in widespread stripping. It may have begun earlier in this region than in the east but it undoubtedly represents the same widespread break, found throughout the Coast Ranges, between the Lower and Upper Cretaceous. Although it is not possible accurately to date this diastrophism in the Santa Lucia Range the evidence that folding, faulting, uplift, and erosion took place somewhere near the close of the Lower Cretaceous is unmistakable; much of the Marmolejo was removed as a result of this orogeny. The entire Coast Ranges were affected but the results were more marked in the Santa Lucia Range than in the Diablo Range and greater in the central part of the Diablo Range than along the west margin of the San Joaquin Valley.

UPPER CRETACEOUS

GENERAL DISCUSSION

Upper Cretaceous sediments are widely distributed not only in the Santa Lucia Range but in the Coast Ranges in general. In the Santa Lucia Range they are exposed at the surface in an area of 425 square miles, approximately 17 per cent of the total area. From various lines of evidence it is believed that by late Upper Cretaceous time the sea covered the entire range, with the possible exception of the extreme northeast part now occupied by the Sierra de Salinas, which, at that time, may have formed a part of Gabilan Island (Fig. 18, paleogeographic map of California at or near the close of the Cretaceous). The present outcrops of Upper Cretaceous sediments in the Santa Lucia Range and adjacent regions are shown on Figure 7.

In the Santa Lucia Range, and in fact over most of the Coast Ranges south of San Francisco Bay, the Upper Cretaceous may be divided into two major groups separated either by an unconformity or by a disconformity. The evidence for an important diastrophism in the Upper Cretaceous is especially clear in the Santa Lucia Range where there is a pronounced angular discordance between the two Upper Cretaceous units that, locally, amounts to as much as 70°. Furthermore, there was widespread uplift and deep erosion, resulting in the partial or even complete removal of many of the earlier Mesozoic rocks, including the early Upper Cretaceous, before the deposition of the later Upper Cretaceous. There also is a marked lithologic difference between the two.

The Upper Cretaceous over most of the state has long been called the Chico group (or formation). The symbol *Kc* (Chico) appears on many published maps as a catch-all for the Upper Cretaceous; unfortunately, Lower Cretaceous beds commonly are included. The name Chico originated in northern California and

it still serves a useful purpose in that region. However, detailed mapping and adequate fossil collections may indicate the advisability of dividing it into formations or even groups in the region north of San Francisco Bay.

In 1915 Anderson and Pack[15] divided the Chico group into the Panoche and Moreno formations, chiefly on the basis of lithology, but these units do not correspond in any way to the Upper Cretaceous groups proposed here. The term Moreno still is useful and, with certain modifications of the original definition of the type section, should be retained in some form. The best approach toward the solution of the Moreno problem appears to have been made by A. S. Huey,[16] who has redefined the term and proposed the name Moreno Grande for the original Moreno and a little of the underlying Panoche. The Panoche, as originally defined and mapped, includes sediments of the upper part of the Franciscan-Knoxville group (Knoxville shale phase), Paskenta, Horsetown, and two Upper Cretaceous units separated by a disconformity. Considering these very diverse elements and the unconformities and disconformities included in the original Panoche, the writer is decidedly of the opinion that the name should be abandoned.

The name Atascadero was given by Fairbanks[17] to all of the Upper Cretaceous sediments of the San Luis region (extreme south end of the Santa Lucia Range), stating it was the local representative of the Chico group. Although most of the Atascadero is equivalent to the Asuncion (uppermost division of the Upper Cretaceous) it also includes shales equivalent to the Jack Creek. Since the two Upper Cretaceous units, the Jack Creek and the Asuncion, are separated by a pronounced unconformity the writer does not believe that the name Atascadero should be used since it would only lead to confusion. The term "Atascadero formation" has been abandoned by the United States Geological Survey[18] in favor of the name "Chico formation."

Taff,[19] working in the extreme north end of the Mount Diablo Range, divided the Upper Cretaceous into three formations, the Chico at the base, unconformable on the Lower Cretaceous, the Panoche resting unconformably on the Chico and grading upward into the Moreno at the top. Although this is a very useful division, and marks a forward step in our understanding of the Upper Cretaceous, it takes great liberties with the names Chico and Panoche, using them in a sense far different from the sense in which they are used in immediately adjacent areas and over the state in general.

[15] Robert Anderson and R. W. Pack, "Geology and Oil Resources of the West Border of the San Joaquin Valley North of Coalinga, California," *U. S. Geol. Survey Bull. 603* (1915).

[16] Personal communication and unpublished manuscript.

[17] H. W. Fairbanks, *op. cit.*, p. 3.

[18] M. Grace Wilmarth, *op. cit.*, p. 85.

[19] J. A. Taff, "Geology of Mount Diablo and Vicinity," *Bull. Geol. Soc. America*, Vol. 46, No. 7 (1935), pp. 1079–1100.

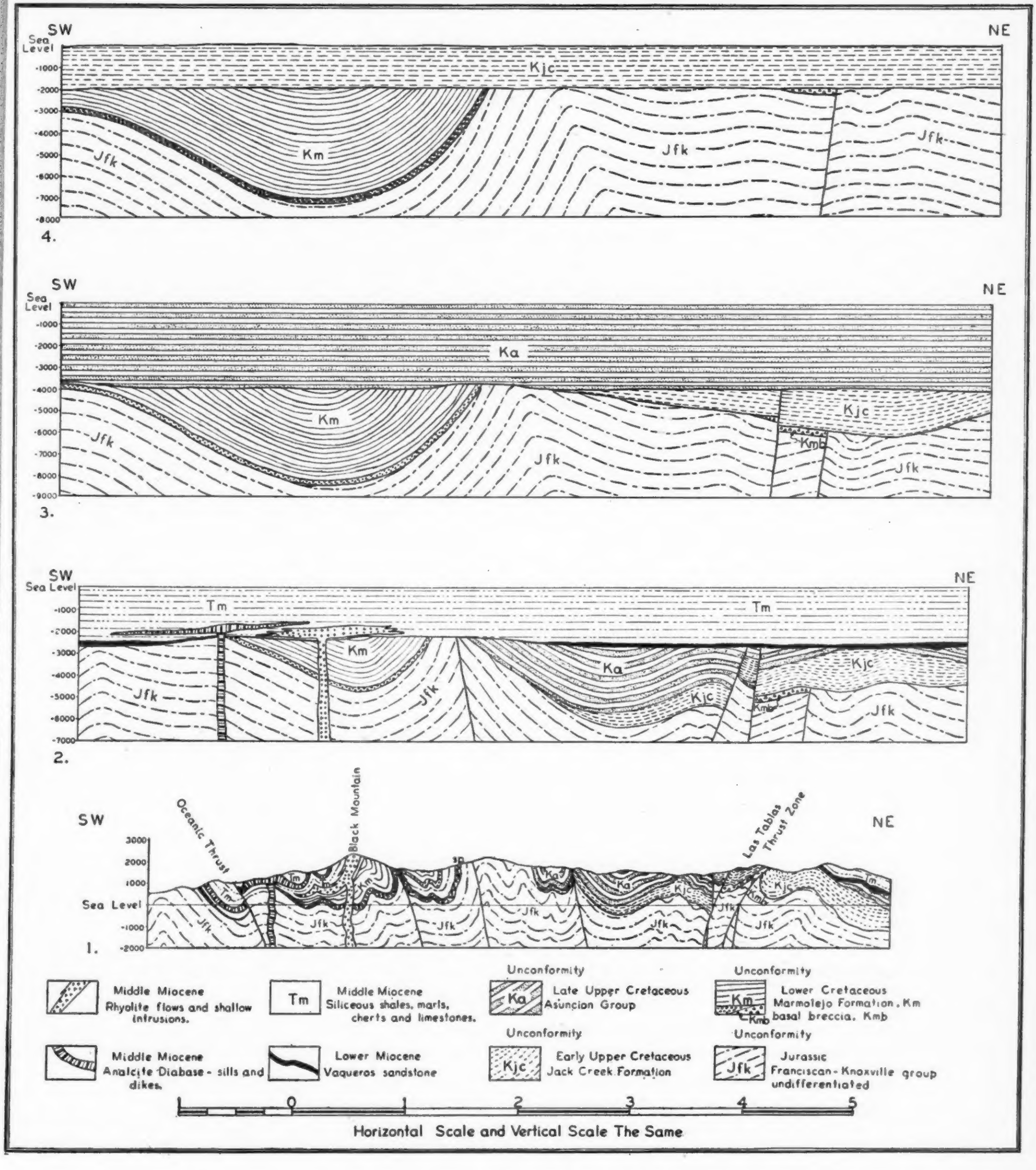

FIG. 8.—Evolution of structure along cross section through south-central part of Adelaida Quadrangle, California, showing relations between various units of Cretaceous and relations to older and younger rocks.

1. Structure as it exists at present.
2. Structure along same section during deposition of middle Miocene.
3. During deposition of Asuncion, late Upper Cretaceous.
4. During deposition of Jack Creek formation, early Upper Cretaceous.

The writer[20] already has presented his objections to the use of "Chico," either as a group term or a formational name, and the arguments need not be reviewed here except to say that he considers it inadvisable to use a name that has been applied in so many different senses, especially when it would include a profound unconformity. In order to facilitate the discussion of the Upper Cretaceous in general over the Coast Ranges between San Francisco Bay and Santa Barbara County and to emphasize the importance of the diastrophism in the Upper Cretaceous the writer[21] proposed that the Upper Cretaceous be divided into the Pacheco and Asuncion groups, separated by the Santa Lucian orogeny. The Pacheco was proposed as a general name for all those sediments, predominantly silty, that accumulated during the depositional interval between the mid-Cretaceous and Santa Lucian orogenies, and the Asuncion for the coarse clastics deposited after the Santa Lucian diastrophism. It was stated at the time:[22]

> The writer dislikes to add new group names to an already overburdened literature, but when the present confused state of the nomenclature and the variety of ways in which many of the names have been used is considered it is believed that the introduction of new terms will serve a useful purpose.

Additional field work has not altered this opinion. However, should it be found possible to redefine the old names, so long applied to the Upper Cretaceous, in such a way as better to take cognizance of the physical history and depositional environments of the time, the writer would be the first to accept the older terms in place of those he has proposed. However, since these groups have been proved satisfactory for field purposes, since they may be recognized and mapped as distinct units in several places in the Coast Ranges south of San Francisco Bay, and since their lithologic characters reflect the physical history of the Coast Ranges, they are still retained for the two major divisions of the Upper Cretaceous.

The name Jack Creek is proposed as a local formational name for the representative of that part of the Pacheco group present in the Santa Lucia Range. The name Asuncion, taken from a locality in the south part of the range, is retained for the coarse clastics deposited after the Santa Lucian orogeny and resting unconformably on all the older rocks. Because of the lack of positive paleontological evidence it is impossible to say exactly how much of the Upper Cretaceous is represented by these two units.

Table I summarizes the Cretaceous of the Santa Lucia Range and gives the probable position of the various units in terms of the usually accepted European stages.

[20] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *California State Div. Mines Bull. 118*, Pt. 2 (1941), pp. 130–34.

[21] *Ibid.*

[22] *Ibid.*, p. 130.

TABLE I

CRETACEOUS OF SANTA LUCIA RANGE

System	*European Stage*	*Group*	*Santa Lucia Range*
Upper Cretaceous	Danian Maestrichtian Senonian	Asuncion group	Asuncion formation
		Santa Lucian orogeny	
	Turonian Cenomanian	Pacheco group	Jack Creek formation
		Mid-Cretaceous disturbance	
Lower Cretaceous	Albian Aptian Barremian Hauterivian Valanginian	Shasta group	Marmolejo formation
		Diablan orogeny	
Upper Jurassic	Tithonian*	Franciscan-Knoxville group	

* Used in the sense of S. W. Muller.

EARLY UPPER CRETACEOUS—JACK CREEK FORMATION

The name is taken from Jack Creek in the southeast part of the Adelaida Quadrangle; the type section is on that part of the creek extending for 1½ miles southeast of the Dover Canyon road where the thickest and most complete section in the range is well exposed.

DISTRIBUTION

Thus far the Jack Creek formation has been positively recognized only in the south part of the Santa Lucia Range where it crops out here and there from the southeast part of the Adelaida to the north-central part of the San Simeon Quadrangle, a distance of more than 20 miles. It is probable that it is present on the northwest but a sufficient amount of detailed work has not been done northwest of the Cape San Martin Quadrangle to make any definite statement regarding its extension in that direction. In the Lucia Quadrangle the Upper Cretaceous was not subdivided by Reiche,[23] and the poorly preserved fossils that were collected are not conclusive. However, some are said to be "Lower Chico," which may indicate the presence of the Jack Creek. The Jack Creek formation is present in the San Luis Quadrangle, in the extreme south end of the Santa Lucia Range, and in the Nipomo Quadrangle, immediately south of the south end of the range, where lithologically similar sediments containing a meager lower Upper Cretaceous fauna (not yet fully studied), lie unconformably below coarse clastics of the late Upper Cretaceous. Lithologically similar sedimentary rocks, occupying the same stratigraphic position, are rather widespread in the central Coast

[23] P. Reiche, "Geology of the Lucia Quadrangle," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 24, No. 7 (1937), pp. 137–44.

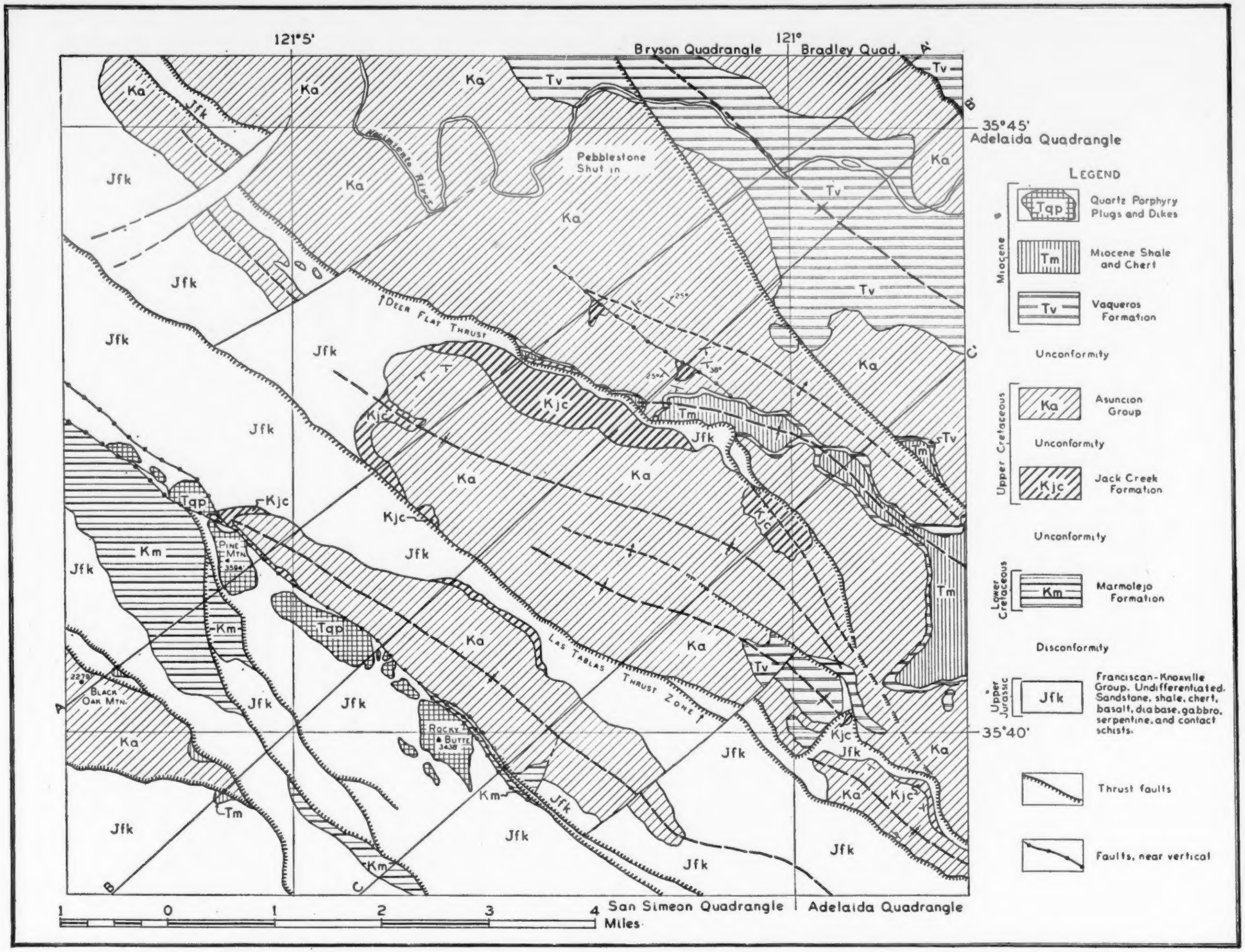

FIG. 9.—Map of parts of Adelaida, Bradley, Bryson, and San Simeon quadrangles showing relations between various Cretaceous units and relations to older and younger rocks. All detail in Franciscan-Knoxville has been omitted. Area shown is approximately 67 square miles.

Ranges. It is believed that the sea in which these sediments, chiefly silts, were deposited covered most if not all of the Coast Ranges. In the Santa Lucia Range, where the Santa Lucian orogeny was most severe, the Jack Creek formation was largely removed before the deposition of the Asuncion.

The Jack Creek formation rests unconformably on the Franciscan-Knoxville group with either a very thin basal conglomerate, nowhere more than 2 or 3 feet thick, or an equally thin basal sandstone. Because of the intense deformation of most of the region many of the contacts are faults but the base is exposed in a sufficient number of widely separated localities to show clearly that the sea in which it was deposited spread quietly over a region of low relief.

LITHOLOGIC CHARACTER

By far the greater part of the Jack Creek formation is made up of light to dark gray sandy clay shales and silts with many thin interbeds of fine-grained, silty, commonly cross-bedded and ripple-marked sandstone. Lenses and thin layers of impure, ferruginous limestone are not uncommon. Lenses of sandstone and gravelly sandstone up to 25 feet in thickness are present in places. The thin sandstones are fine-grained and silty but the thicker lenses may be medium-grained. Unfortunately, no mechanical or mineral analyses have been made of these sandstones.

A very characteristic feature of the Jack Creek formation is the presence, throughout its extent in the Adelaida and San Simeon quadrangles, of shale-matrix conglomerates containing highly polished pebbles. Ordinarily the pebbles are not concentrated into lenses but occur scattered through the silts at several horizons. Most of the pebbles are small, averaging well under an inch, but some attain a diameter of 3–4 inches. Here and there the shale-matrix conglomerates pass into more ordinary conglomerates having a sandy matrix and closely crowded pebbles and cobbles. In this type, with a sand rather than a silt matrix, the average size of the pebbles is greater and the polish inconspicuous or absent. The pebbles in the shales have a remarkably high polish over the entire surface of the pebbles, even including the concavities. Rough, fractured surfaces of pebbles, broken either in transit or in the environment of deposition, are also highly polished but the broken surfaces are not obliterated or modified except on sharp edges, which are somewhat worn. The high polish, characteristic of these pebbles in the shales and siltstones, is usually ascribed to wind action. However, these pebbles are not generally faceted to the extent of ventifacts. Since the pebbles with a sand matrix are not polished to any appreciable extent and since even the rough broken edges of pebbles in silts are polished it is evident that the polishing took place in the environment of deposition, which, very clearly, was shallow marine, as shown by the presence of marine fossils and the strongly cross-bedded and ripple-marked silty sandstones. Therefore, it is clearly indicated that the high polish did not result from the same causes that brought about the rounding of the pebbles. The strong cross-bedding ordinarily shown by even the

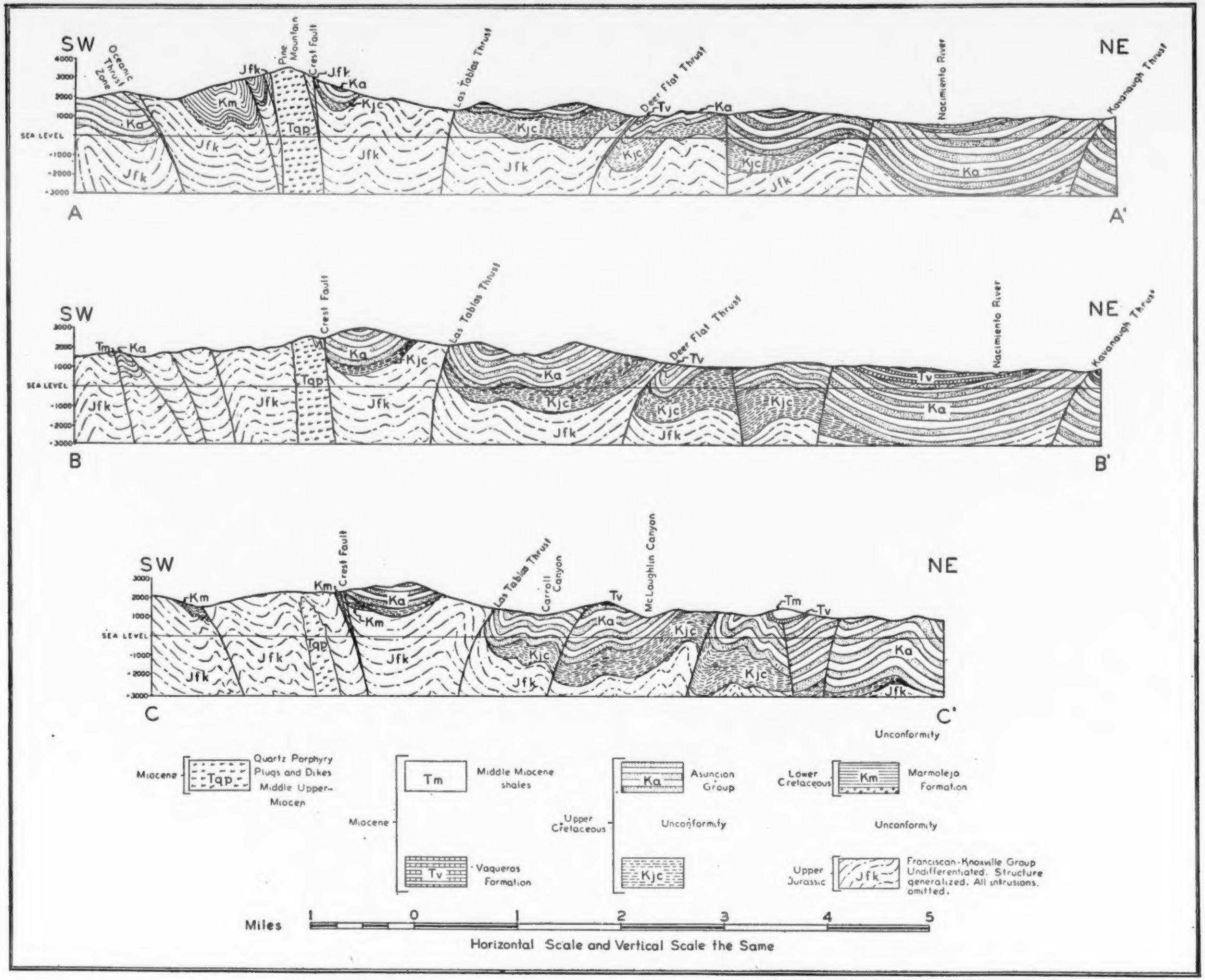

FIG. 10.—Cross sections to accompany map shown in Figure 9.

thin sandstones and the presence of marine fossils clearly indicate a very shallow marine environment of deposition. In the opinion of the writer the high polish shown by the pebbles in the shales was caused by the constant agitation of the silts containing the pebbles by tidal and other currents in exceedingly shallow marine waters. The sharp angular fragments making up the silts acted as a natural abrasive.

A few of the polished pebbles are shown in Figure 13. The largest was broken, either in transit or in the site of deposition, yet the rough, broken surface is as highly polished as the rounded area. This pebble is a dense feldspar porphyry; the pitted surface is the result of slight weathering of the plagioclase phenocrysts and microlites.

The pebbles in the Jack Creek formation, both in the shale matrix and ordinary conglomerates, are predominantly of hard resistant rocks, both Franciscan-Knoxville and the pre-Mesozoic crystallines being represented; the latter are more abundant. The most common Franciscan-Knoxville pebbles are of dense radiolarian cherts but pebbles of sandstone, diabase, and basalt are present. The pre-Franciscan rocks are represented by pebbles of various types of dense porphyries, feldspar, quartz, and quartz feldspar porphyries, gray and pink quartzites, dense, black, recrystallized cherts, flow-banded rhyolites, and aplites. Granodiorite and schist pebbles are comparatively rare. In general the pebbles are rather well rounded.

RELATION OF JACK CREEK FORMATION TO OLDER AND YOUNGER ROCKS

Where the original depositional contact is exposed the Jack Creek formation everywhere rests with marked unconformity on the Franciscan. The best exposures of this contact are in the south-central and central parts of the Adelaida Quadrangle and in the north and northeast parts of the San Simeon Quadrangle. In the Adelaida Quadrangle the basal beds consist of 1–2 feet of fine silty sand that passes in a short distance upward into silty gray shales. The first shale-matrix conglomerates appear several hundred feet above the base.

In the San Simeon Quadrangle the base is either a fine silty sand or a thin conglomerate or conglomeratic sandstone not more than 3 feet in thickness. In the thin basal conglomerate, Franciscan pebbles equal or exceed the pre-Franciscan porphyries and quartzites.

The predominantly fine-grained character of the Jack Creek formation and the thinness or absence of a basal conglomerate indicate that the early Upper Cretaceous sea spread quietly over an area of comparatively low relief. That there had been an orogenic episode prior to its deposition is shown by the widespread removal of the Lower Cretaceous and a part of the Franciscan-Knoxville group. However, erosion had reduced any highlands formed as a result of the mid-Cretaceous diastrophism and had left an area of low relief, at least in the south part of the Santa Lucia Range, over which the early Upper Cretaceous sea spread. The fine-grained Jack Creek formation was deposited in shallow

marine water in a slowly sinking basin where sedimentation appears to have kept pace with the downsinking. The writer has no intention of implying that the accumulation of the sediments was the cause of downsinking. In his opinion basin sinking was the result of comparatively weak tangential compression that gradually increased in magnitude and finally culminated in the Santa Lucian orogeny.

As a result of the Santa Lucian orogeny the Jack Creek formation, as well as many of the earlier Mesozoic rocks, were partly or completely removed prior

FIG. 11.—Detail of Jack Creek silty shales, Swamp John Creek, northeast part of San Simeon Quadrangle. Asuncion conglomerates and sandstones rest on these shales with angular discordance of 40° a few hundred feet away (left of picture).

to the deposition of the coarse clastics of the Asuncion. Where the Jack Creek formation was not completely removed there is abundant evidence that it was tilted, folded, faulted, and strongly eroded prior to the deposition of the Asuncion. The angular discordance between the two varies from a few degrees to 70°. In the northeast part of the San Simeon Quadrangle, on two unnamed creeks, small areas of the Jack Creek shales are exposed along a pre-Miocene fault. Here the visible angular discordance varies from 30° to more than 40°, and the Asuncion conglomerates contain abundant débris of the Jack Creek, particularly the hard limestone lenses. In the south-central part of the Adelaida Quadrangle, 1–2 miles

FIG. 12.—Folded, faulted, and overturned shales of Jack Creek formation. Below (northeast of) Las Tablas thrust zone. Near head of Tobacco Creek, San Simeon Quadrangle.

southeast of Josephine School, the angular discordance is approximately 70°. In the same quadrangle, near the headwaters of Jack Creek, gently dipping Asuncion sandstones pass across a fault between Franciscan and Jack Creek shales. The pre-Asuncion drag in the shales against the fault is shown in Figure 14. The structural relations are shown in Figures 8 and 10. The coarse clastics of the Asuncion group in many places transgress the Jack Creek shales and rest on the Marmolejo formation or, more commonly, on the Franciscan-Knoxville rocks, in the south part of the Santa Lucia Range. On the northwest, in the central and north parts of the range, the Asuncion rests in most places on the older crystalline rocks, either Sur schists or Santa Lucia plutonics; in other places, however, even in the north part of the range, they rest on the Franciscan.

AGE AND THICKNESS

Fossils are exceedingly rare in the Jack Creek formation and the few that have been collected have not been studied in detail. *Belemnites* were obtained in the northeast part of the San Simeon Quadrangle and *Inoceramus* in the south-central part of the Adelaida Quadrangle. According to S. W. Muller, these are

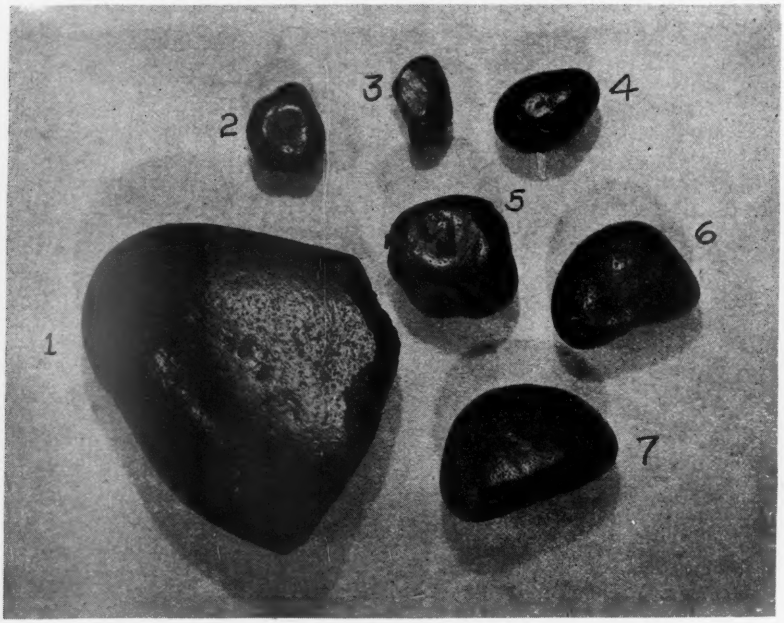

FIG. 13.—Highly polished pebbles from shale-matrix conglomerate of Jack Creek formation, Adelaida Quadrangle. Natural size.
1. Dense brownish gray feldspar porphyry, pre-Franciscan.
2, 3. Red radiolarian chert, veined with quartz. Franciscan-Knoxville.
4, 5. Dense recrystallized black chert, pre-Franciscan.
6. Gray quartzite, Sur series.
7. Fine-grained black feldspar porphyry, pre-Franciscan.

Upper Cretaceous, probably "early Chico." No more precise paleontological information is available.

However, there is indirect evidence that the Jack Creek formation is rather early Upper Cretaceous. Both the Jack Creek and the Asuncion are unquestionably Upper Cretaceous, yet they are separated by a profound unconformity. The Jack Creek and earlier Mesozoic rocks were folded, faulted, uplifted, and removed either in whole or in part from wide areas prior to the deposition of the Asuncion. Although the diastrophism may have occupied a relatively brief inter-

val of Upper Cretaceous time the widespread removal of a thick prism of Mesozoic rocks must have required an appreciable time; hence, it is believed that the Jack Creek formation is probably early Upper Cretaceous.

Additional information regarding the date of the diastrophism between the Jack Creek and the Asuncion, the Santa Lucian orogeny, is found in other places

FIG. 14.—Jack Creek shales, showing drag along pre-Asuncion fault, extreme left. Fault is just outside left margin. Coarse biotitic Asuncion sandstone passes across fault, which is between Jack Creek shales and Franciscan-Knoxville. On tributary of Jack Creek, central part of Adelaida Quadrangle.

in California. In the Mount Diablo region, and southeastward along the east side of the Diablo Range, Senonian and Maestrichtian conglomerates containing fossiliferous boulders derived from Turonian sediments are found, indicating, of course, that the Santa Lucian orogeny took place between the Turonian and the Senonian. It is believed that the Jack Creek formation is pre-Senonian but, at present, it is impossible to state how much of the Cenomanian and Turonian it represents. The possible correlation of the Jack Creek formation with other Upper Cretaceous units in the Coast Ranges is discussed in a following section.

Because of the strong folding, faulting, and erosion between the two Upper

Cretaceous formations it is impossible to obtain any evidence regarding the original thickness of the Jack Creek formation. On Jack Creek, south of the Dover Canyon Road, Adelaida Quadrangle, it is approximately 2,900 feet thick. In the northeast part of the San Simeon Quadrangle it is 1,600 feet thick. It is impossible to estimate how much was removed by erosion prior to the deposition of the Asuncion. Beds believed to be equivalent to the Jack Creek in the Diablo Range have a thickness of 5,000–8,500 feet.

SANTA LUCIAN OROGENY

Throughout the Coast Ranges between San Francisco Bay and Santa Barbara County there is evidence of a pronounced break in sedimentation in the midst of the Upper Cretaceous. The evidence for diastrophism at this time is especially clear in the south Santa Lucia Range; hence, this diastrophism has been called the Santa Lucian orogeny by the writer.[24] As stated previously, it is believed to have taken place between the Turonian and Senonian.

The evidence on which this orogeny is based in the Santa Lucia Range is touched upon under the discussion of the Jack Creek formation and is again referred to under the Asuncion group. In the Santa Lucia Range the evidence is clear and convincing; it was the strongest orogeny to affect this region between the deformation of the Sur series and the late Pliocene orogeny that so profoundly affected practically all of the Coast Ranges. The extent of this diastrophism and its effect upon subsequent folding and faulting and in the shaping of the Coast Ranges had never been fully realized. Although it did not destroy the great Mesozoic geosyncline in which the Franciscan-Knoxville group and the Cretaceous was deposited it greatly modified the basin and apparently caused an eastward shift in its main axis. The widespread stripping caused by the Santa Lucian orogeny and by uplift in the early Eocene, which appears to have followed lines established in the Upper Cretaceous, permitted the exposure of large areas of the crystalline basement complex, resulting in great variation in the thickness of the readily deformable sedimentary prism. Thus, the Santa Lucian orogeny had a profound effect upon the evolution of the Coast Ranges.

The intensity of the Santa Lucian orogeny died out eastward yet its effect is clearly discernible even along the east flank of the Diablo Range. Taff[25] reports an unconformity between the "Chico" and the "Panoche" in the Mount Diablo region. The use of these terms has been commented upon previously; there seems to be little doubt that Taff's "Chico" is equivalent to the Jack Creek and the "Panoche" to the Asuncion.

Heavy conglomerates appear for the first time about 6,000–8,000 feet above

[24] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *California Div. Mines Bull. 118*, Pt. 2 (1941), pp. 130–32.

[25] J. A. Taff, "Geology of Mount Diablo and Vicinity," *Bull. Geol. Soc. America*, Vol. 46, No. 7 (1935), pp. 1079–1100.

the base of the "Panoche" (or rather above the base of the Upper Cretaceous part of the "Panoche" as originally mapped). These conglomerates contain abundant boulders of the underlying Cretaceous which is predominantly silty, and some of these boulders contain Turonian fossils; they also contain débris of the Franciscan. These conglomerates occur along the east flank of the Diablo Range. A few specific localities are those on Garzas, Quinto, and El Puerto creeks, and on Ortigalita Creek near the old Ortigalita School (now no longer there, but whose location is shown on the sheet of the Panoche Quadrangle). It is doubtful that these heavy conglomerates all occur at the same horizon; they are all lenses and can not be traced continuously. They do not represent an unconformity locally but they definitely reflect an uplift, or uplifts, on the west and the exposure of the early Upper Cretaceous sediments. The writer regards these conglomerates as the result of the Santa Lucian orogeny, which caused uplift and widespread stripping in the west Coast Ranges but which did not necessarily cause a complete withdrawal of the Upper Cretaceous sea from a part of the region that is now the east flank of the Diablo Range. However, there is evidence of a strong unconformity in the Upper Cretaceous farther south along the west side of the Diablo Range in the Dark Hole Quadrangle. There is a thick section of Upper Cretaceous sediments beneath the Eocene along Arroyo Pinoso, northeast of Castle Mountain. Ralph Stewart collected Cretaceous fossils near the top of this section; according to W. P. Popenoe[26] these fossils are early Upper Cretaceous. Near Castle Mountain the crest of the range is occupied by a syncline in the late Upper Cretaceous sandstones that rest unconformably on Lower Cretaceous shales. Thus, in a distance of less than a mile the entire section of the early Upper Cretaceous, at least 8,000 feet thick, exposed along Arroyo Pinoso at the north, is missing in the Castle Mountain Range.[27]

The Santa Lucian orogeny also exerted a profound effect on the character of the sediments, especially in the Santa Lucia Range. The predominantly fine silty sediments of the Jack Creek formation are in strong contrast to the coarse detritus of the Asuncion.

The writer is well aware that there are local disconformities and gaps in the late Upper Cretaceous section along the east side of the Diablo Range but he wishes to make it clear that these are not directly referable to the Santa Lucian orogeny. The writer has observed local disconformities in the Moreno on Los Banos Creek and in the north part of the Pacheco Quadrangle. At the latter

[26] W. P. Popenoe, personal communication, 1942.

[27] The structural relations in this region are correctly shown on the extreme northeast end of cross section I of the writer's 1941 sections of the Coast Ranges but unfortunately the Upper Cretaceous sediments below the Eocene along Arroyo Pinoso are shown as Asuncion, late Upper Cretaceous, whereas the paleontological evidence indicates that they are early Upper Cretaceous. The writer wishes to take this opportunity to correct an error largely due to the haste with which these cross sections were prepared. The unconformity in the Upper Cretaceous was known to the writer in 1936 and the information conveyed to R. D. Reed, who refers to it in a footnote on page 11, *Structural Evolution of Southern California* (1936)

locality *Pholas*-bored blocks of Moreno sandstone occur in a local conglomerate in the Moreno. None of these breaks can be traced for any distance; they appear to be caused by very local warping or possibly even by over-filling of the basin by rapidly accumulating sediments. Though locally important, they are much later than, and not comparable with, the Santa Lucian orogeny.

In summary, it may be stated that the diastrophism in the midst of the Upper Cretaceous resulted in strong folding, faulting, uplift, and erosion in the Santa Lucia and parts of the Diablo Range, but that the Upper Cretaceous sea was never completely driven from some areas along what is now the east flank of the Diablo Range, where deposition appears to have been continuous. However, in the latter region the coarse conglomerates, some containing fossiliferous Upper Cretaceous boulders, appear to be the result of Santa Lucian movements to the west.

ASUNCION FORMATION, LATE UPPER CRETACEOUS

The Asuncion formation is the most widespread and the thickest Cretaceous unit in the Santa Lucia Range as well as in the entire Coast Ranges south of San Francisco Bay. It contains a fairly abundant fauna that is definitely later than the Turonian, but since the fauna has not been completely worked out it is not known just how much of the Senonian, Maestrichtian, and Danian is represented. Although the fauna has not been completely studied enough is known to indicate strongly that the late Upper Cretaceous sea in which the Asuncion was deposited did not reach all parts of the Santa Lucia Range at the same time. Some of the higher parts were not flooded until very late in the Upper Cretaceous.

The type section of the Asuncion is in the Asuncion Grant, in the southeast part of the Adelaida Quadrangle where there are good exposures of all phases along Santa Rita Creek, the Templeton-Cayucos road, and on the road past Asuncion School. Better type sections are near Bryson and along the Nacimiento River in the Bryson Quadrangle, but since both the names Bryson and Nacimiento already have been used the name Asuncion has been chosen. In the field the names "Bryson sandstone" and "Godfrey Flat shales" were used for different phases of the Asuncion.

DISTRIBUTION

Asuncion sediments are found almost throughout the Santa Lucia Range from the south part of the Monterey Quadrangle southeastward to and beyond the south limit of the range and from the Pacific Ocean almost to the Salinas Valley. They are also widely distributed throughout the Coast Ranges. It is believed that by the close of the Upper Cretaceous, the sea covered all of the region now occupied by the Santa Lucia Range except the extreme north part, the Sierra de Salinas, which was probably a part of Gabilan Island, a comparatively small area probably not more than 80 miles long and 25 miles wide, that was never submerged during the Upper Cretaceous. The distribution of the Asuncion in the Santa Lucia Range is shown in Figure 7.

LITHOLOGIC CHARACTER

The greater part of the Asuncion is made up of rather coarse biotitic feldspathic sandstone with thin partings of highly carbonaceous shale. Coarse conglomerates are numerous and clay shales and silts occur here and there. In the areas that have been mapped by the writer, in the central and south part of the range, coarse and fine sediments have been separated in mapping, as the distribution of these types gives important information regarding the direction of derivation of the detritus. However, they are of comparatively little stratigraphic value as conglomerates and sandstones commonly grade in a short distance into shales. Rapid lateral variation is especially well illustrated in the north-central part of the Adelaida Quadrangle and the south-central part of the Bradley Quadrangle, where the most extensive areas of shale are found. Lateral variation is not confined to this locality but is characteristic of the late Upper Cretaceous in general. Because of common and abrupt lateral variation it is difficult, and in places impossible, to divide the late Upper Cretaceous into lithologic units that are satisfactory stratigraphic divisions in any large area. In the opinion of the writer it would also handicap the division of the late Upper Cretaceous into faunal stages based on foraminifera. Apparent gaps and irregularities in local sections might well be the result of the gradation of a shale into sandstone or even conglomerate.

Lenses of conglomerate, or thick zones of alternating sandstone and conglomerate, are common throughout the Asuncion. They are, as a rule, poorly bedded, except where there are numerous interbeds of sandstone. No shale-matrix conglomerates have been observed. The pebbles, cobbles, and boulders are ordinarily subrounded to rather well rounded; the degree of rounding depends somewhat on the location and the nature of the rock. The pebbles, cobbles, and boulders occur in a sandstone matrix similar to the ordinary sandstones. They are generally well cemented with calcium carbonate and minor amounts of iron oxide but in breaking the fracture follows around the constituents, not across them. In fresh cuts the matrix is blue-gray, weathering to shades of yellow, brown and red-brown; on upland surfaces of moderate relief they commonly break down and can only be followed by pebbles in the soil.

The nature of the constituents is fairly constant in rather wide areas but varies somewhat with the location, as does the average size of the pebbles. In the central and south part of the range there is a very definite increase both in average size and amount of Franciscan débris toward the west. There is also a local northward increase in average size and proportion of granodiorite cobbles in the Bryson and Cape San Martin quadrangles, toward present exposures of large areas of granodiorite.

Nearly everywhere pre-Franciscan débris greatly predominates over Franciscan, but there are places, especially along the west side of the central and south part of the range, where the Franciscan predominates.

The pre-Franciscan detritus (Sur series and Santa Lucia granodiorite) consist

of various types of porphyries with small phenocrysts of quartz, feldspar, or both set in a dense or fine-grained groundmass. Other rocks commonly present are recrystallized flow-banded rhyolites, light to dark gray quartzites, white quartzites, pink to red quartzites, black recrystallized chert, granodiorite (including related plutonic rocks), pegmatites, aplites, quartz-mica schists, garnetiferous quartz-mica schists, and graphitic marble. Pebbles of Franciscan chert are not uncommon and with other Franciscan types, become more abundant on the west. Débris of the ferruginous Jack Creek limestones and sandstones are abundant in places, particularly in the northeast part of the San Simeon Quadrangle.

Asuncion conglomerates containing notable amounts of Franciscan-Knoxville and some Marmolejo débris occur in the San Simeon and Piedras Blancas quadrangles. In the former, 3–4 miles northeast of San Simeon, there is an isolated area of coarse Asuncion sandstones and conglomerates preserved beneath a northeast-dipping thrust (cross section *AA*, Fig. 10). This has a length of 4 miles and a maximum width, east and west, of 2 miles. All of the conglomerates contain abundant pebbles, cobbles, and boulders of Franciscan-Knoxville chert, basalt, diabase, and sandstone, as well as the typical pre-Franciscan assemblage. The basal conglomerates, exposed in two places along Little Pico Creek, rest with an angular discordance of 35°–45° on steeply dipping Franciscan-Knoxville sediments and contain angular to subrounded blocks of Franciscan sandstone up to 5 feet in diameter; blocks of basalt and diabase up to 3 feet in size also are abundant as well as well rounded boulders of granodiorite up to 2 feet in diameter.

In the north part of the Piedras Blancas Quadrangle, at an elevation of 1,350 feet between Arroyo Hondo and Arroyo de los Chinos, Asuncion sandstones and sandy shales rest unconformably on Franciscan sedimentary and volcanic rocks with a coarse basal conglomerate containing angular blocks of Franciscan chert and sandstone up tc 3 feet in diameter; well rounded pre-Franciscan pebbles and cobbles also are present. The basal conglomerates pass upward into coarse biotitic sandstones and sandy shales, dipping northeast, that continue northeastward almost to the top of Pine Mountain, elevation 2,600 feet, where they are overridden by Franciscan along a northeast-dipping thrust.

There is abundant evidence to support the statement that the Asuncion becomes coarser and contains a greater amount of Franciscan débris toward the west, indicating derivation from that direction, in the south and central part of the Santa Lucia Range.

Certain statements regarding Cretaceous conglomerates in general have appeared in several published reports that are so at variance with the writer's observations that he wishes to take this opportunity to discuss the subject. Reed[28] in a discussion of Cretaceous conglomerates in general and those on Quinto Creek, on the east side of Diablo Range, in particular, states (page 100):

> The pebbles consist of two types: igneous and metamorphic rocks of different kinds,

[28] Ralph D. Reed, *Geology of California* (1933), pp. 100–02.

derived obviously from older formations; and shale, sandstone, or conglomerate, derived from the Cretaceous itself. If fragments of the second type have fossils, as they occasionally do, the fossils belong to approximately the same horizon as the conglomerate bed in which they occur.

Also on pages 101 and 102 he states:

The occurrence of Cretaceous pebbles in Cretaceous strata has been noted by many observers. The pebbles comprise angular shale fragments, and angular to subangular fragments of well-cemented sandstone which may be fine-grained or pebbly, fossiliferous or barren.

He then refers to the Quinto Creek conglomerates and suggests that the Cretaceous débris in the sandstones and conglomerates came from "superficial portions of already deposited beds which became cemented almost contemporaneously with deposition." In the first quotation Reed refers to Cretaceous conglomerates in general, in the second to a specific locality. However, he implies that Cretaceous débris may be abundant in Cretaceous conglomerates at any horizon and is the expected, not the exceptional phenomenon. Furthermore, he states that fossiliferous boulders contain fossils that belong to approximately the same horizon as the conglomerate bed in which they occur. These statements are so opposed to the observations of the writer that he must take exception to them.

Cretaceous shale fragments are, in places, abundant in Cretaceous sandstones and conglomerates at any horizon. Shale flake sandstones and conglomerates are also common in the Franciscan-Knoxville and in the Lower Cretaceous. However, the presence of fossiliferous boulders of Cretaceous sandstone and conglomerate do not occur indiscriminately at any horizon and the fossils are not of approximately the same horizon as the conglomerate bed in which they occur, unless by "the same horizon" is meant the Upper Cretaceous as a whole. Upper Cretaceous débris, in some places fossiliferous, does occur in Upper Cretaceous conglomerates but the occurrence is not without meaning and does not take place at any horizon. Such occurrences have been referred to previously; they are the result of the Santa Lucian orogeny.

The phenomenon mentioned by Reed (p. 102) on Quinto Creek is of common occurrence in the thick conglomerate lenses in the midst of the Upper Cretaceous and is caused by submarine slumping, the result either of the rapid dumping of coarse detritus on unconsolidated muds or the result of contemporaneous earthquakes.

The often repeated statement that Upper Cretaceous conglomerates are commonly filled with contemporaneous Upper Cretaceous débris is a fallacy that bids fair to be accepted as an established fact through repetition in print. It is a minor example of what has been so aptly called "the indestructibility of error" by Simpson.[29]

[29] George Gaylord Simpson, "Mammals and the Nature of Continents," *Amer. Jour. Sci.*, Vol. 241, No. 1 (1943), pp. 1–31, particularly the discussion of the *Hipparion*-bridge and accordion continents, pp. 22–27.

By far the greater part of the Asuncion is made up of fine- to coarse-grained biotitic feldspathic sandstones; these also form the matrix of the conglomerates and occur as thin interbeds in the shales. They are commonly cross-bedded and give every indication of having been deposited in shallow water; apparently they are all marine. Ordinarily they are firmly cemented with calcium carbonate, generally somewhat ferruginous; although well cemented they break around rather than across the grains. The degree of cementation of the sandstones (and the conglomerates as well) varies considerably but may be correlated roughly with the intensity of deformation. In regions where the beds have been strongly folded, faulted, and, consequently, greatly jointed, they are, nearly everywhere, much more firmly cemented than in areas of relatively low dips. In areas where the dips are comparatively low the sandstones, particularly those interbedded with shales, may be so poorly cemented as to be loose and friable. The degree of cementation appears to be a function of the ease of penentration of former ground waters containing substances, chiefly calcium carbonate, in solution.

On fresh surfaces, they are gray to blue-gray, weathering to shades of brown and red-brown on oxidation of the iron. Although they generally have a much higher biotite content than the Franciscan sandstones it is in places difficult to differentiate them where both are deeply weathered. They differ from the Franciscan sandstones in that there has been no recrystallization of the finer clayey constituents except locally along exceptionally strong zones of folding and faulting, or where they have been very deeply buried. Thin interbeds of silty shale are not uncommon; both the shales and the sandstones contain abundant small carbonized plant fragments.

Almost all the sandstones support a heavy plant growth and make up most of the densely brush-covered areas in the range. This is in striking contrast to the comparatively barren areas underlain by the Jack Creek shales; the contrast in cover is shown in Figure 15.

The writer is indebted to C. E. Van Gundy and C. L. Goudy for 19 mineral and 6 mechanical analyses of Asuncion sandstones from the Adelaida Quadrangle; these are shown in Table II and Figure 16. Although these analyses are from a stratigraphic thickness of fully 5,000 feet and are representative of the Asuncion sandstones in a zone along the east side and a part of the crest of the Santa Lucia Range, through the Adelaida, Bradley, and Bryson quadrangles, they can not be considered as representative of the Asuncion in all localities. Mineral analyses transverse to the range, instead of parallel with it, undoubtedly would show greater differences in the heavy separates than the examples shown in Table II. Since the conglomerates show a marked increase in the proportion of Franciscan-Knoxville débris toward the west it is more than probable that the heavy separates would show a corresponding increase in characteristic Franciscan-Knoxville minerals. One reason for the scarcity or absence of characteristic schist minerals such as glaucophane actinolite, lawsonite, practically pure albite, zoisite, pargasite, and epidote is the fact that there are only a few small areas of pneu-

matolytic contact-metamorphic schists in the Franciscan-Knoxville in the south part of the range. Actinolite, present here and there, and some of the sphene may have been derived from the pneumatolytic schists; any of the other minerals might have been derived by a reworking of Franciscan-Knoxville sandstones as well as directly from granodiorites and crystalline schists.

Standard procedure was followed in making the mineral and mechanical analyses; 150–250 grams of each sample were broken into pieces approximately

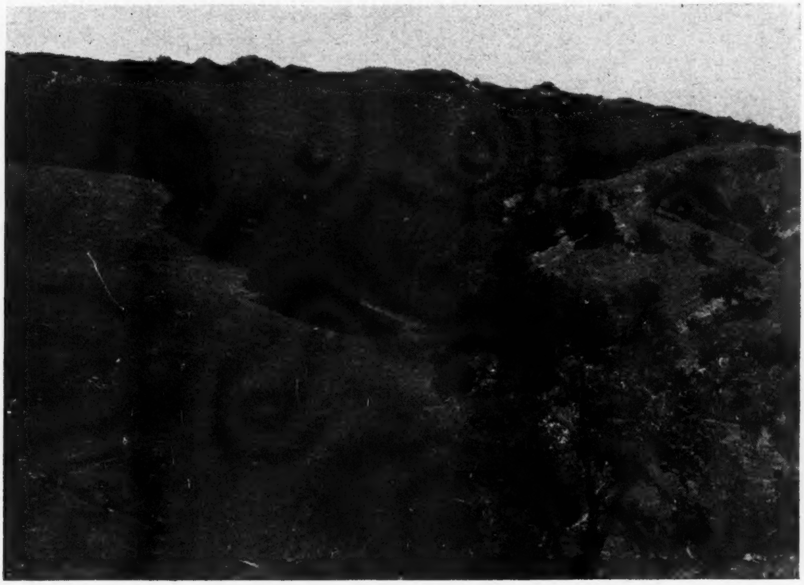

FIG. 15.—Typical exposures of Jack Creek shales and Asuncion sandstones. Practically barren, rolling foreground is underlain by shales; brush-covered ridge in background is made up of sandstones. Locally there is a fault between shales and sandstones. Central part of Adelaida Quadrangle.

½-inch in diameter and then treated with hydrochloric acid to dissolve the calcareous and ferruginous cementing material. After thorough washing and drying the material was run through 2-, 1-, ½-mm. and 80- and 150-mesh sieves. Histograms were constructed from the weights of the individual fractions. The ½-mm. to 80-mesh fraction was separated into light and heavy constituents by bromoform having a specific gravity of 2.9. The percentage of minerals in the heavy separate was computed on the actual count of 150 grains or more; in the light separate by count and estimate of 100 grains or more. Heavy separates range from 0.20 to 2.24 per cent and average 0.63 per cent; of this 9.6 per cent is biotite. However, biotite is much more abundant in the sandstones than would

TABLE II
ASUNCION SANDSTONES

Light separates computed to 100%	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	*Average*
Quartz	55	50	50	50	60	65	65	55	65	65	70	60	60	60	65	60	65	65	65	60
Total feldspar	30	35	35	40	30	25	23	30	25	25	20	25	30	30	25	25	20	25	30	28
Orthoclase	10	6	8	10	6	10	4	5	8	10	7	8	10	9	7	10	7	8	6	8
Albite-oligoclase	13	17	11	12	15	11	12	15	9	10	8	12	14	10	13	9	9	10	9	12
Oligoclase-andesine	7	12	16	18	9	4	7	10	8	5	5	10	6	11	5	6	4	7	15	8
Muscovite	5	3	1	1	3	2	2	3	1	2	1	3	1	1	1	3	1	2		2
Rock fragments*	10	12	14	9	7	8	10	12	9	8	9	12	9	9	9	12	14	8	5	10
Heavy separates computed to 100%																				
Actinolite	P		P			P														
Allanite			P																	
Biotite	17.3	8.0	7.5	10.4	8.0	7.3	10.4	7.5	5.7	16.2	8.5	10.6	10.1	9.5	7.6	17.4	5.5	11.1	4.3	9.6
Brookite		P	P	P																
Chlorite	7.1	P	P	7.3	5.1	1.6	2.1	1.8	.5	.5	7.2	.5	1.1	P	5.0	1.5	5.8	P	P	3.4
Garnet																				4.7
Colorless	P	5.5	P		P	3.7	P	.8	P	1.4	P	P	P	1.2	1.3	1.0		5.6	1.1	
Pink	1.7	4.8	P	3.2	3.4	2.3	4.8	2.6	P	2.8	1.7	1.9	5.2	2.5	4.1	.6	3.2	3.8	1.6	
Amber	2.6	P	1.1	3.2	1.8	P		1.2	1.1	P	2.6	1.0			P	P	3.2			
Hornblende	1.7	P	1.1	1.2	P		P	P		1.3	1.7			P	P		1.1			
Ilmenite	11.5	15.9	3.5	P	12.6	15.8	12.1	10.1	15.0	10.4	12.5	17.2	10.5	8.8	10.5	P	3.5	4.6	3.5	8.5
Magnetite	8.9	11.1	8.7	2.1	10.3	11.8	8.7	9.2	9.0	18.5	7.9	25.0	8.6	10.3	8.1	2.1	8.7	P	8.8	9.8
Sphene	11.6	5.5	21.2	9.5	5.1	3.6	9.4	5.5	11.6	10.5	3.4	11.2	7.3	5.2	9.4	9.5	P	5.5	P	8.5
Tourmaline	P		P		1.6	.9	P	P	1.1	P		P			4.1		P	3.1	3.7	
Zircon	8.0	5.5	5.8	5.3	10.2	16.2	8.6	11.4	5.2	8.0	10.3	5.2	11.4	11.2	6.6	12.6	11.7	15.0	11.2	9.4
Rock fragments*	28.7	43.5	50.0	59.0	32.0	35.0	43.0	47.0	48.0	38.0	35.0	32.0	44.0	55.5	43.0	65.0	51.0	54.0	62.0	45.3

P: Present.
* Includes leucoxene and myrmekite.
The heavy mineral separates on the Grades from 1/2 mm. to 1/10 mm. average 0.63%.
1 to 4 inclusive from C. E. Van Gundy, "The Relations of the Upper Cretaceous and Martinez in the Northern Part of the Adelaida Quadrangle, California," unpublished master's thesis, General Library, University of California, Berkeley.
5 to 19 inclusive from C. L. Goudy, "A Structural and Petrographic Study of the Vaqueros and Associated Formations in the Southeast Portion of the Adelaida Quadrangle, California," *ibid.*
The locations of the sandstones studied are as follows.
All are from the Adelaida Quadrangle, south part of the Santa Lucia Range. 5 to 19 are in, or just north of, the Asuncion Grant, the type section.

1. Sec. 19, T. 25 S., R. 10 E., 800 feet W. and 900 feet S. of NE. corner, Sec. 19. Coarse fossiliferous sandstone, Nacimiento River.
2. Sec. 20, T. 25 S., R. 10 E., south bank of Nacimiento River. Fine- to medium-grained, fossiliferous sandstone.
3. Sec. 12, T. 26 S., R. 9 E., NE. corner, Sec. 12. Medium-grained, fossiliferous sandstone.
4. Sec. 19, T. 25 S., R. 10 E. Extreme SE. corner, Sec. 19. Fine-grained sandstone.
5. Sec. 18, T. 27 S., R. 11 E., SE. corner, Sec. 18. South of Jack Creek. Fine-grained gray sandstone.
6. Sec. 18, T. 27 S., R. 11 E., SW. corner, Sec. 18. Coarse sandstone interbedded with conglomerate.
7. Sec. 23, T. 27 S., R. 10 E., NE. corner, Sec. 23. Medium-grained sandstone. East of Dover Canyon.
8. Sec. 23, T. 27 S., R. 10 E., SE. corner, Sec. 23. Fine-grained sandstone.
9. Sec. 25, T. 27 S., R. 10 E., 1 mile NW. of Asuncion School. Coarse sandstone interbedded with conglomerate.
10. Sec. 31, T. 27 S., R. 11 E., 750 feet SW. of Asuncion School. Medium-grained sandstone.
11. Sec. 31, T. 27 S., R. 11 E., 50 feet stratigraphically above 10. Coarse sandstone.
12. Sec. 32, T. 27 S., R. 11 E., $\frac{1}{2}$ mile E. of Asuncion School. Fine sandstone.
13. Asuncion Grant, where the 1,250-foot contour passes through the o of ASUNCION. Medium-grained sandstone.
14. Where NE. boundary of Asuncion Grant crosses Santa Rita Creek. Fine-grained sandstone.
15. Sec. 14, T. 27 S., R. 10 E., SW. $\frac{1}{4}$, NE. $\frac{1}{4}$ Sec. 14. Coarse sandstone.
16. Sec. 25, T. 27 S., R. 10 E., center of section. $1\frac{1}{2}$ miles, NW. of Asuncion School. Fine-grained sandstone.
17. Sec. 20, T. 27 S., R. 11 E., $\frac{1}{2}$ mile W. of Jack Creek. Medium-grained sandstone.
18. Sec. 19, T. 27 S., R. 11 E., $\frac{1}{2}$ mile S. of Jack Creek. Medium-grained sandstone.
19. Jack Creek, Paso de Robles grant. Near base of Asuncion. Medium-grained sandstone.

be indicated by this figure. Large flakes are abundant practically everywhere in the sandstones.

As shown in Table II the average quartz and feldspar content of 19 sandstones from the Adelaida Quadrangle is 60 and 28 per cent, respectively. This is very similar to the same averages for 12 Franciscan sandstones from the same region (61.7 and 30.4 per cent) but lower in feldspar and higher in quartz than

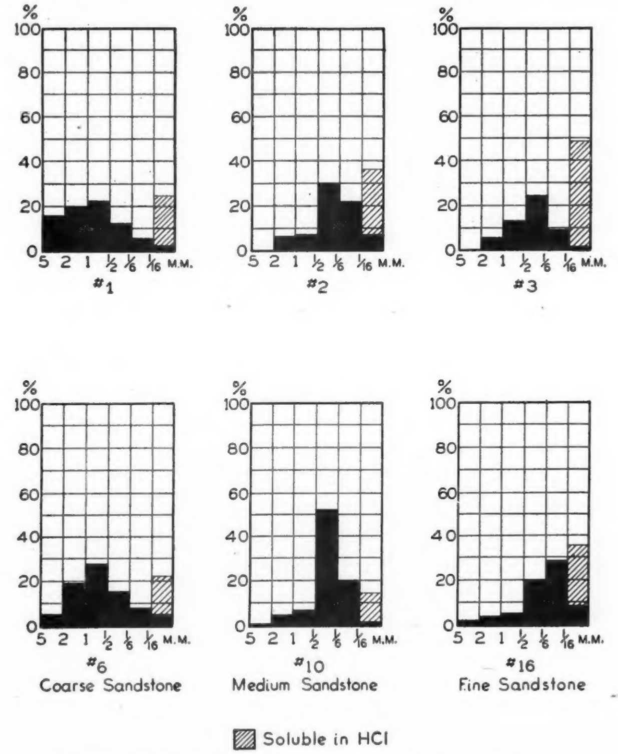

FIG. 16.—Mechanical analyses of Asuncion sandstones from Adelaida Quadrangle. 1, 2, and 3 by C. E. Van Gundy from north part of quadrangle; 6, 10, and 16 by C. L. Goudy from southeast part of quadrangle.

the general average for 17 Franciscan sandstones (56.2 and 37.1 per cent).[30] There are not enough published mineral analyses of Upper Cretaceous sandstones to justify a positive statement as to regional variation in the quartz-feldspar ratio but from the few analyses available and from purely megascopic examinations, which can not be greatly relied upon, it does not appear that there is any sig-

[30] N. L. Taliaferro, "The Franciscan-Knoxville Problem, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 2 (February, 1943).

nificant or regular change from one part of the state to another. In other words, Upper Cretaceous sandstones appear to be fairly uniform in mineral composition.

The only noteworthy difference in the mineral analyses of the 19 Asuncion sandstones shown in Table II and those of 12 Franciscan sandstones from the same region is in the biotite content. Even though it is assumed that all of the chlorite in the sandstones came from biotite originally, still the Cretaceous sandstones contain at least twice as much as the Franciscan. Field observations also show that the Cretaceous sandstones contain a much larger percentage of biotite; where both are deeply weathered this is a fairly satisfactory means of differentiating them.

The individual grains of the sandstones are predominantly subangular but many are subrounded or even fairly well rounded, probably the result of wave action in the basin of deposition. The feldspar grains are not as fresh, on the average, as those in the Franciscan sandstones; orthoclase shows partial, or even fairly complete, alteration into kaolin. The plagioclase is somewhat altered but is ordinarily fresher than the orthoclase. The mineral assemblage indicates derivation from a crystalline source, largely granodiorite, quartz-mica schists and garnetiferous quartz-mica schists. As previously stated, it is believed that mineral analyses of Asuncion sandstones farther west would show a greater proportion of Franciscan débris as Franciscan pebbles become more abundant in that direction. The general lack of rounding and the alteration of some of the feldspars indicate that mechanical disintegration predominated, but that there was a certain amount of chemical weathering. The great abundance of carbonized plant remains shows that the land area supplying the detritus was well wooded. The conditions were somewhat similar to those prevailing during the deposition of the early part of the Franciscan but the relief of the land area does not appear to have been as great or the climatic conditions so rigorous.

Reed[31] states:

> In summary, the sandstone of the Cretaceous is remarkably uniform in lithology and shows ample evidence of derivation in largest part from areas composed dominantly of granitic rock. The facts so far brought to light fail entirely to give aid and comfort to the holders of the hypothesis that upthrust Franciscan "blocks" contributed in any notable degree to the detritus of the Cretaceous sea.

The writer is in agreement with the first sentence. However, the relatively large amount of Franciscan material in the Asuncion conglomerates in the west part of the Santa Lucia Range and the east side of the Diablo Range is convincing evidence that, in some places, Franciscan areas contributed detritus to the Upper Cretaceous sea. These areas, however, were not necessarily upthrust fault blocks.

A Franciscan area of considerable extent stood above sea-level west of the present coast line along the central and south part of the Santa Lucia Range, at least during the deposition of the early part of the Asuncion. Another elevated

[31] R. D. Reed, *Geology of California*, p. 104.

area underlain by Franciscan rocks was in what is now the north-central part of the Diablo Range; however, this latter area appears to have been completely submerged before the close of the Cretaceous.

Six mechanical analyses are shown in Figure 16; the numbers refer to the sandstones in Table II. The histograms indicate that the sandstones, especially those of medium grain, are fairly well sorted and contain little clay. However, this is not true of all Upper Cretaceous sandstones. Reed[32] states that the few mechanical analyses available (at the time, 1933) agree in showing a rather low degree of sorting, similar to Goldman's delta types.[33] No such similarity exists, however, between the latter and the mechanical analyses shown in Figure 16. The histograms of the Asuncion sandstones show much greater similarity to Goldman's lagoon and open-ocean types than to delta types. Undoubtedly, a large number of mechanical analyses of Upper Cretaceous sediments from many localities would show characters indicating deltas, estuaries, lagoons, and open oceans as all such conditions probably existed. Reiche[34] states that the deltaic deposition of the Upper Cretaceous of the Lucia Quadrangle is suspected but not proved. Some of these sediments may have formed on deltas but the glauconitic silts, described by Reiche, are hardly likely to have formed in such an environment. However, both the histograms and the fauna of the Asuncion in the central and south part of the Santa Lucia Range indicate deposition in the open ocean.

No mineral or mechanical analyses have been made of the Asuncion silts; however, the sandstones interbedded with, and grading into them are identical with the sandstones just described. Some of the silty shales of the Asuncion are very similar in appearance to the Jack Creek shales except that the former are somewhat sandier in general and contain a larger proportion of interbedded sandstone. They are entirely lacking in shale-matrix conglomerates. Foraminifera are abundant in the Asuncion shales but scarce or lacking in the Jack Creek.

The thin shale partings in the massive sandstones are ordinarily very sandy and highly carbonaceous; they are generally light to dark gray in color, shading into black with an increase in plant material. In areas made up predominantly of alternating shales and thin sandstones the prevailing color of the exposures is dark gray to black. Areas in which shales predominate over sandstones, especially where the folding has not been extreme, are generally of moderate relief and relatively free from brush. Typical examples of such areas are: Godfrey Flat, north part of the Adelaida Quadrangle, and Bear Trap, Oak, and Italian Flats in the Bryson Quadrangle. The largest area of shales in the Asuncion formation is in the north part of the Adelaida and the south part of the Bradley quadrangles; here shales predominate in a stratigraphic thickness of approximately 1,500 feet.

[32] R. D. Reed, *op. cit.*, p. 104.

[33] Marcus I. Goldman, "The Petrography and Genesis of the Sediments of the Upper Cretaceous of Maryland," *Maryland Geol. Survey*, "Upper Cretaceous," Vol. 1 (1916), pp. 111–82.

[34] Parry Reiche, "Geology of the Lucia Quadrangle, California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 24, No. 7 (1937), p. 144.

In the central and south part of the range the distribution of the Asuncion shales is significant. The thickest and most extensive areas of shales are found in the most easterly exposures of the late Upper Cretaceous. Although coarse sandstones and even conglomerates occur in the same region the increase in the proportion of shales toward the west is regarded as due, at least in part, to greater distance from the source.

The writer previously (1941, 1943) has discussed the question of a land mass such as "Salinia" during the Mesozoic and has presented evidence against its existence. The distribution of shale in the Asuncion is regarded as additional evidence. If "Salinia" stood as a land mass during the Asuncion there should be a general increase in grain size toward its borders. No such increase exists. In the south part of the Santa Lucia Range there is a definite decrease in the proportion of coarse clastics from west to east, toward, not away from, the west margin of this hypothetical land mass. Furthermore, there is a large proportion of shale in late Upper Creatceous beds north of Parkfield, 25 miles northeast, on the supposed eastern border of "Salinia."

Although there is abundant evidence, from deep wells, proving the absence of both Franciscan-Knoxville and Cretaceous rocks from the Gabilan Mesa, there are thick sections of both on its immediate borders (which correspond with the borders of "Salinia") in the general latitude of the central and south part of the Santa Lucia Range. Furthermore, in the north part of the range there are extensive areas of Cretaceous sediments well within the limits of "Salinia."

In the opinion of the writer there still existed, in the Upper Cretaceous, a broad seaway across the Gabilan Mesa ("Salinia") into the interior of California. At the beginning of the deposition of the Asuncion there appear to have been islands along the present trend of the crest of the Diablo Range, but it is believed that even these were completely submerged by the close of the Cretaceous. The only area, within the limits of "Salinia" as originally defined,[35] that probably stood above sea-level throughout the Upper Cretaceous, was the present site of the Gabilan Range and the Sierra de Salinas. The scanty evidence for this land area, Gabilan Island, will be reviewed.

Less information is available regarding the distribution of coarse and fine clastics in the north part of the Santa Lucia Range because so much of the Cretaceous has been removed or covered by Tertiary sediments. However, from the areas still remaining certain tentative conclusions may be reached. Reiche[36] states that in the Lucia Quadrangle, about 35 miles southeast of the north end of the range:

> It appears that the bulk of the Chico was laid down in a sea advancing rather rapidly from the southwest. High relief of the surface thus covered is suggested by the great variation in thickness of the basal conglomerate, and by its coarseness in the southern part of the area.

[35] R. D. Reed, *op. cit.*, pp. 12, 31, and 292 and Figures 6 and 20.

[36] Parry Reiche, *op. cit.*, p. 143.

Fossil evidence indicates that these "Chico" beds are Asuncion. An examination of the sections given by Reiche also indicates an increase in fine sediments toward the northeast. The incomplete section at Deer Pasture (most northwesterly section) shows a considerably greater proportion of shale than sections on the southwest. On the east, in the Junipero Serra and King City quadrangles, the Upper Cretaceous is predominantly coarse sandstone, indicating an increase in grain in this direction. Although the evidence afforded by these isolated areas of Upper Cretaceous sediments can not be regarded as conclusive, it indicates a general decrease in grain from the southwest, followed by a general increase toward the west, tending to show that there was a land mass north and east of the King City Quadrangle.

THICKNESS OF ASUNCION

Two factors militate against the preservation of a complete section of the Asuncion: (1) intense diastrophism during the Tertiary, especially in the late Pliocene, resulting in strong folding and faulting, the removal of large areas of the Cretaceous and their burial beneath thrusts; (2) the deposition of thick Tertiary sediments over much of the region. The base is exposed in many places but the writer never has seen any sediments he could be sure represented the original top. Furthermore, even in sections in which the base is exposed, the upper part either has been cut off by faulting or buried beneath later sediments. A continuous section has not been found in which both the base and what could be considered even the approximate top are exposed.

The thickest section in the central and south part of the range is exposed in the Bryson Quadrangle west of the Nacimiento River, a little north of the Shut In, where there is a continuous section, that does not appear to be faulted, fully 6,000 feet thick, chiefly coarse sandstones and conglomerates. Neither top nor bottom is exposed. On the west the section is bounded by a high-angle thrust fault that brings the Franciscan over the Asuncion and on the east, along the Nacimiento River it is overlain by Tertiary land-laid redbeds, fully 3,000 feet thick and filled with coarse débris from the Asuncion.

In the north part of the Adelaida Quadrangle Asuncion sandstones and silts are exposed in an anticline that is 10 miles northeast of the crest of the range. On the southwest flank of the anticline more than 4,500 feet of late Upper Cretaceous sediments are exposed. The base is not visible and the Cretaceous is unconformably overlain by the Paleocene, Tertiary redbeds, and Vaqueros (lower Miocene).

In the southeast part of Adelaida Quadrangle there is a continuous steeply dipping section along Jack Creek 4,800 feet in thickness. The base, resting on Jack Creek shales, is exposed, but both Upper Cretaceous units are overlain by the Vaqueros, with a basal conglomerate containing *Pholas*-bored blocks of both formations, which transgress more than 7,000 feet of Upper Cretaceous sediments in a distance of 3 miles.

In the Lucia Quadrangle, Reiche estimates that the Upper Cretaceous has a maximum thickness of 6,000 feet; however, the thickest measured section is 4,270 feet.

Practically all that can be said definitely is that the maximum thickness of

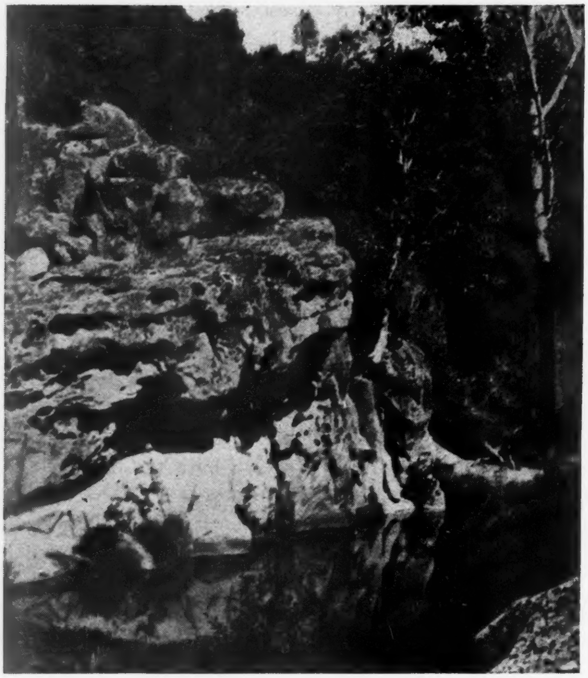

FIG. 17.—Typical exposure of Asuncion sandstone along upper part of Nacimiento River, Bryson Quadrangle. Photo by C. L. Heald.

the Asuncion is greater than 6,000 feet. The writer is of the opinion that the original thickness was considerably greater, an opinion based on the relations in the vicinity of the 6,000-foot section in the Bryson Quadrangle. The base is not exposed and there is no direct means of estimating the thickness of the lower part beneath the fault; it is believed to be considerably in excess of 1,000 feet. Along the Nacimiento River in this region the Asuncion is overlain by a thick section of Tertiary redbeds that contain many heavy conglomerates filled with angular blocks of the Asuncion sandstones and conglomerates. The volume of reworked Cretaceous in these beds is remarkable and indicates extensive erosion of the earlier sediments. It is believed that the original maximum thickness must have been close to 10,000 feet.

Little can be said regarding original variation in thickness but there is some evidence that it might have been considerable. Unlike the sea in which the Jack Creek was deposited, and which spread over an area of low relief, the Asuncion sea advanced over a region of considerable relief. As is shown in the discussion of the fauna, there is some evidence that the advancing sea first flooded the lower areas, the higher areas not being covered until well along in the deposition of the Asuncion. No quantitative figure is obtainable that would give even an approximate value for the original variation in thickness.

ALTERATION OF ASUNCION

In general the Asuncion is little altered and it is clear that, although it commonly stands at high angles and is even overturned, the deformation took place, in most places, under a comparatively shallow cover, probably rarely more than 5,000 feet. However, there are local areas where the Asuncion has been somewhat altered with the development of a slight slaty cleavage in the shales. This change ordinarily occurs in comparatively narrow zones and appears to be related to zones of faulting. A good example occurs along the coast in the vicinity of Slate's Springs, Lucia Quadrangle, where the sandstones are somewhat crushed and the shales are slightly slaty. In places the shales and sandstones appear as though welded together. Fairbanks[37] was so impressed with the apparent metamorphism of these fossiliferous beds that he considered them to be Franciscan; he states as follows.

> The sandstone matrix is so metamorphosed as to resemble a crystalline rock. At Slate's Springs the conglomerate is followed upward by sandstones, slaty shales, and jasper. The whole series is considerably metamorphosed and all the members filled with ramifying quartz veinlets. The shale in its metamorphism has assumed the appearance of a fine-grained mica schist.

C. H. Davis[38] also called the beds slates, referred them to the Franciscan and offered fossil evidence that they are Jurassic.

Nomland and Schenck have reviewed the evidence and collected fossils from the same locality and have shown the beds described by both Fairbanks and Davis to be late Upper Cretaceous.[39] As has been shown by Reiche,[40] the apparent recrystallization of the Upper Cretaceous at Slate's Springs is the result of intense local crushing along a fault zone.

Both Fairbanks and Nomland and Schenck mention the presence of chert in the beds at Slate's Springs. The writer wishes to take this opportunity to state

[37] H. W. Fairbanks in the *12th Ann. Rept. of the State Mineralogist* (Sacramento, California, 1893–94), p. 519.

[38] C. H. Davis, "New Species from the Santa Lucia Mountains, California, with a Discussion of the Jurassic Age of the Slates at Slate Springs," *Jour. Geol.*, Vol. 21 (1913), pp. 453–58.

[39] J. O. Nomland and H. G. Schenck, "Cretaceous Beds at Slate's Hot Springs, California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 21 (1932), pp. 37–49.

[40] Parry Reiche, *op. cit.*, p. 142.

emphatically that he never has seen any contemporaneous deposits of chert in any part of the Upper Cretaceous. This statement is based on detailed studies of a number of areas and on reconnaissance trips to most of the Upper Cretaceous localities in the state. The beds at Slate's Springs are intensely faulted, locally silicified, and extensively veined. The jasper or chert reported at this locality is the result of imbrication along a thrust fault, small slices of true Franciscan being present along the fault, and to local silicification of the shales.

There are other areas where the Asuncion has been rendered somewhat slaty either by faulting, strong folding, or both. Another area is on San Miguel Creek in the Cape San Martin Quadrangle where beds consisting of alternations of sandstones and shales present the same general appearance as those at Slate's Springs, the result of close folding and faulting.

In places, especially along faults, the Asuncion is extensively veined with both quartz and calcite. These are commonly very small gash veins that can be traced but a few inches or feet. However, in the central part of the Bryson Quadrangle there are fairly large veins of coarse-grained calcite, containing cinnabar and pyrite along a transverse fault in the Asuncion. This has been described briefly by Eckel, Yates, and Granger[41] who state:

> The rocks exposed in the vicinity of the mine consist of coarse-grained conglomeratic sandstone and shale and siltstone. All are of Late Cretaceous age. The principal structural feature is a northeastward trending fault zone which brings coarse-grained sandstone on its southeast side against shale on the northwest. According to Taliaferro (personal communication) this is a tear fault that extends between two major northward-trending thrust faults.

Cinnabar occurs as crusts in the fault breccia and in calcite veins along the fault. The writer has traced this fault, which trends N. 63° E., more than 4 miles. Near its northeast end it offsets the Asuncion-Vaqueros contact a distance of approximately 1,000 feet. The movement appears to be chiefly horizontal, the south side having moved northeast with respect to the north side. Aside from the veins and the mechanical brecciation along the fault, the Asuncion is completely unaltered. Many similar transverse tear faults cut the Upper Cretaceous but they produce no alteration, other than brecciation. This is in striking contrast to the alteration found along the much stronger northwest-trending thrust faults.

In a few places the Asuncion is hydrothermally altered, also along thrust faults. The best example of this type of alteration, which kaolinizes the feldspar, develops considerable sericite, and changes the color of the sandstones to white, occurs in the San Simeon Quadrangle on the North Fork of Pico Creek, 1½ miles southeast of Blackoak Mountain.

The entire Cretaceous of the Santa Lucia Range is remarkably free from contemporaneous igneous activity. There is no evidence anywhere of any interbedded pyroclastic rocks and there are no intrusives of Cretaceous age. Fairbanks re-

[41] E. B. Eckel, R. G. Yates, and A. E. Granger, "Quicksilver Deposits in San Luis Obispo County and Southwestern Monterey County, California," *U. S. Geol. Survey Bull. 922R* (1941), pp. 579–80.

ported that the long line of quartz prophyry plugs extending from San Luis Obispo westward to Moro Rock were intruded during the Cretaceous, but since they do not cut the Cretaceous anywhere in that region the evidence is not convincing. Identical quartz porphyry plugs occur in similar elongate zones in several places in the Adelaida and San Simeon quadrangles where they intrude everything up to the middle Miocene. They evidently ascended through wet Miocene sediments as they show increasing autobrecciation upward, finally breaking through onto the sea floor; trains of débris from the plugs are interbedded with middle Miocene shales and later shales pass uninterruptedly across the plugs. These plugs, like those in San Luis Valley, were intruded during the Miocene.

In summary, it may be stated that the Asuncion, although strongly folded, faulted, and lithified, and commonly standing at high angles, is practically unaltered except along thrust zones or in regions of exceptionally tight folding. There was no contemporaneous igneous activity. This statement holds true for the Jack Creek formation also.

FAUNA AND AGE OF ASUNCION

Although the Asuncion is the most fossiliferous of all the Cretaceous units in the Santa Lucia Range, fossils are far from common except locally at certain horizons, where they may be very abundant. In the course of 12 years' work in the region many fossiliferous localities have been discovered, extending from the southeast part of the Adelaida to the northeast part of the Cape San Martin Quadrangle, nearly 50 miles. Fossils also have been collected by Reiche in the Lucia Quadrangle, by Nomland and Schenck near Slate's Springs in the same quadrangle, and by Trask in the Point Sur Quadrangle. Fossils, therefore, have been found in the Asuncion almost the entire length of the range.

Determinable fossils do not occur in the entire thickness of the Asuncion but are confined to the upper 1,500–2,500 feet, with the exception of an area in the northeast part of the Cape San Martin Quadrangle where only the upper part appears to be represented. Fossils have been found in several localities in the lower part, notably along Jack Creek and Dover Canyon, but all are casts of small, apparently unornamented pelecypods that, according to B. L. Clark, are indeterminate. Their only value is to indicate that the sediments are marine. It is unfortunate that the lower part of the Asuncion is practically unfossiliferous; however, since the Jack Creek, on which the Asuncion rests unconformably, is known to be Upper Cretaceous in age there can be no doubt that the lower part of the Asuncion is also Upper Cretaceous.

Fossils occur rather abundantly in three main areas in the central and south part of the range: (1) along the road east of Asuncion School, in the Asuncion grant, a few hundred feet below the Vaqueros contact; (2) throughout the north part of the Adelaida, the south part of the Bradley and the southeast part of the Bryson quadrangles; (3) in the northwest part of the Bryson and the north part

of the Cape San Martin quadrangles. It is only along the belt in which these areas lie, east of the crest of the range, that the upper part of the Asuncion is preserved.

Practically all of the many individual localities in these three general areas have yielded the same fauna; faunal lists from practically all localities where reasonably complete collections have been obtained and where the sediments are lithologically the same are essentially the same. The three commonest species found in practically all localities where sandstones predominate, in order of their abundance, are: *Glycymeris veatchii* Gabb, *Turritella chicoensis* Gabb, sub sp. *perrini* Merriam, and *Turritella chaneyi* Merriam. Shale and silt faunas rarely contain these forms. However, fossiliferous sandstones and conglomerates clearly pass into shales; faunal differences appear to be due to environmental conditions of deposition rather than to age.

Probably less than half of the fossils collected has been determined, even generically, but it is believed that a sufficient number have been identified positively to afford a reasonable basis for a broad correlation with both the Santa Ana Mountains and the west side of the San Joaquin Valley.

The writer is indebted to Alex Clark, B. L. Clark, and H. G. Schenck for the following composite list of fossils from the upper part of the Asuncion in the Adelaida, Bradley, Bryson, and Cape San Martin quadrangles.

Acila (*Truncacila*) *demessa* Finlay, Schenck
Aphrodina nitida Gabb
Astarte cf. *lapidis* Packard
Brachydontes n. sp.
Clisocolis dubius Gabb
Coralliochama cf. *orcuta* White
Crassatella n. sp.
Cucullaea n. sp.
Dentalium cf. *cooperi* Gabb
Glycymeris veatchii Gabb
Inoceramus cf. *whitneyi* Gabb
Nemodon n. sp.
Opus triangulata Cooper
Ostrea sp.
Parapachydiscus sp.
Polinices sp.
Pugnellus (*Conchothyra*) *hamulus* Gabb
Septifer n. sp.
Tessarolax distorta Gabb
Trigonarca n. sp.
Trigonocallista varians Gabb
Turritella chaneyi Merriam
Turritella chicoensis Gabb, sub. sp. *perrini* Merriam
Volutoderma averilli Gabb

This list consists of 24 genera, 15 definitely determined species, 3 referred species, and 6 that are regarded as new species. In addition there are trigonias, baculites, brachiopods, at least 3 genera of ammonites, as well as pelecypods and gastropods that have not been determined. This material is in the Museum of Invertebrate Paleontology, University of California, Berkeley.

As previously stated, fossils are abundant only in the upper part of the Asuncion, the lower containing only indeterminate casts. This is true except in the north and northeast part of the Cape San Martin Quadrangle where fossils extend almost to the base of the Asuncion. However, the fauna in this locality is identical with that occurring far above the base at the southeast, the beds being essentially the same lithologically and, while not continuously traceable, both localities lie along the same trend and in the same belt; both are thought to represent the same general stratigraphic horizon. It is significant that the conglomerates become coarser northwest and contain large blocks of granodiorite, schist, and marble, which are exposed in the Cape San Martin, Junipero Serra,

and Lucia quadrangles. It is believed that, in the region where fossils extend practically to the base, the sea in which the Asuncion was deposited did not reach the higher areas of crystalline rock until comparatively late in Asuncion time. The thick section, beneath the fossiliferous beds, on the southwest, south, and southeast is not represented locally. This area may have lain on the southwest edge of Gabilan Island, which continued to shrink in size as the late Upper Cretaceous sea advanced northeast.

In the ensuing discussion of the age and possible correlation of the Asuncion, it must be remembered that it is only the age of the fauna, well up in the Asuncion, that is being considered. The age of the 3,000 to possibly 6,000 or 7,000 feet beneath the fossiliferous horizons can only be determined by inference and by comparison with other areas and by relation to the Jack Creek formation.

According to B. L. Clark, this fauna contains a great many genera and species in common with the so-called "Garzas fauna," the highest Cretaceous along the west side of the San Joaquin Valley, north of Coalinga, and in his opinion is unquestionably of the same age. This statement has been read and approved by Clark.

It is to be regretted that W. P. Popenoe, who has done so much careful work on the fauna of the Upper Cretaceous, has not had the opportunity of studying this material. However, the writer has compared the list here given with Popenoe's list from the Santa Ana Mountains[42] and is struck with the similarity of the Santa Lucia material with all the divisions of Popenoe's *Glycymeris veatchii* fauna. Only one of the species in the writer's list extends downward into Popenoe's *Glycymeris pacificus* fauna. This is *Opus triangulata* Cooper which is reported from 6 localities in the *G. veatchii* zone and from one near the top of the *G. pacificus* zone. However, this is not regarded as particularly significant since it is only reported as a referred species (*O.* sp. cf. *O. triangulata*) in Popenoe's list. Only one of Popenoe's very abundant fossils, and one which gives its name to the lowest division of the *Glycymeris veatchii* fauna does not appear on the list given here. This is *Turritella chicoensis*. Regarding this omission a word of explanation is necessary. *T. chicoensis* repeatedly has been reported to the writer in many of the Asuncion collections but since it is not reported by Merriam,[43] who had access to all of the collections, it has been omitted. Some of the very abundant Asuncion turritellas may very well be the same as *T. chicoensis* in the Santa Ana Mountains.

At present it is impossible to attempt any subdivision of the *G. veatchii* fauna in the Santa Lucia Range similar to the divisions in the Santa Ana Mountains because of the great difference in the structural conditions in the two regions. In the Santa Lucia Range, and especially in the general belt in which the fossils occur, the Cretaceous is strongly folded and faulted and commonly unconforma-

[42] Willis P. Popenoe, "Upper Cretaceous Formations and Faunas of Southern California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 2 (1942), pp. 162–87, especially the check list, Fig. 4, and the columnar sections, Fig. 3.

[43] C. W. Merriam, "Fossil Turritellas from the Pacific Coast Region of North America," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 26 (1941), pp. 1–214.

bly covered by Tertiary sediments. Because of great structural complexity and rapid lateral gradation of lithologic types it is impossible to arrange the localities in any definite stratigraphic order as was done by Popenoe in the little disturbed section in the Santa Ana Mountains. The only statement that can be made is that the fossil collections come from the upper 1,500–2,500 feet of Asuncion sediments.

Although only a part of the Asuncion fauna has been determined the great similarity between it and the *Glycymeris veatchii* fauna is regarded as highly significant. Furthermore, the Asuncion fauna certainly appears to be identical with the Garzas fauna (upper part of the Moreno) along the west side of the San Joaquin Valley. The writer feels justified in correlating, at least tentatively, the Asuncion fauna, as listed here, the Garzas fauna, and the *Glycymeris veatchii* fauna of the Santa Ana Mountains. It is not believed that any attempt should be made, at present, to correlate this fauna with Cretaceous sections in north California although there are indications that it may be very widespread.

In the Santa Cruz Quadrangle a belt of Cretaceous sediments 13 miles long and 2 miles wide extends along the coast from Año Nuevo Bay to the mouth of Pescadero Creek. The fauna, as listed in the Santa Cruz folio,[44] contains species common to the *Glycymeris veatchii* and Ascuncion faunas and there seems little doubt that the Asuncion is represented in this region. However, it is not known how much of the belt is Asuncion and how much is earlier Cretaceous.

Edwards[45] has reported Martinez (Paleocene) fossils from several localities in the Adelaida and Bryson quadrangles. The first locality mentioned, that near the center of the NE. $\frac{1}{4}$ of Sec. 30, T. 25 S., R. 10 E., Adelaida Quadrangle, is Paleocene, which rests unconformably on the Asuncion. The localities on Las Tablas Creek, near its junction with the Nacimiento River, and in the Bryson Quadrangle are not Paleocene but Asuncion and contain the fauna previously listed. The presence of ammonites in these localities is conclusive proof of their Cretaceous age. The Paleocene has a very limited distribution in the Adelaida Quadrangle; none is known to occur in any of the adjacent quadrangles. As shown later, there is considerable difficulty in differentiating the Asuncion and Paleocene where only small collections are available. Small Asuncion collections usually have been reported to the writer as Paleocene before being carefully studied; there is a remarkable similarity between many elements of the faunas.

Some Asuncion shales contain abundant foraminifera and it should be possible to zone that part of the formation largely made up of shale on this basis. The writer has collected foraminifera from a number of localities and submitted them to micropaleontologists, but thus far to the writer's knowledge, only one collection has been studied.

Foraminiferal shales collected at two localities along the north bank of the

[44] J. C. Branner, J. F. Newson, and Ralph Arnold, "The Santa Cruz Quadrangle," *U. S. Geol. Survey Geol. Atlas 163* (1909), p. 3.

[45] M. G. Edwards, "Some Eocene Localities in Salinas Valley District, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17 (1933), p. 81.

Nacimiento River in the extreme north part of the Adelaida Quadrangle and the south part of the Bradley Quadrangle were submitted to Lois T. Martin of Stanford University. The specific localities are: NE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 19, Adelaida Quadrangle, and SW. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 18, Bradley Quadrangle. Both are in T. 25 S., R. 10 E., and both contain the same fauna. The two localities have a stratigraphic separation of about 300 feet, that in section 19 being the higher. The faunule is as follows.

Bulimina prolixa
Haplophragmoides sp.
Palmula cf. *pilulifera*
Robulus macrodiscus
Silicosigmoilina californica
Siphogenerinoides cf. *clarki*

The above faunula places this sample in the Upper Cretaceous, approximately the same age as the Moreno shale north of Coalinga.[46]

The samples were sent by Miss Martin to Stanley Carlson, who kindly checked the faunule and reports the same assemblage. He states:[47]

> I am not familiar with any Cretaceous faunas outside of the San Joaquin and Sacramento Valleys but would compare the samples with those we have found in the lower part of the Moreno formation and the very uppermost part of the Panoche. At the present time we find it difficult to pick the Moreno-Panoche contact faunally, as well as lithologically.

Since the Moreno-Panoche contact is gradational it is always difficult to decide on any exact contact and such a decision would be purely arbitrary. Furthermore, because of the lenticular nature of the sediments, there is considerable disagreement as to the contact, even at the type section of the Moreno.

The specimens containing the foraminifera were obtained from shales interbedded with sandstones containing the megafauna listed previously. They are slightly higher stratigraphically than the beds near the mouth of Las Tablas Creek from which Edwards reported Paleocene fossils and afford additional proof, if any were needed beside the presence of ammonites, that the supposed Paleocene locality actually is Upper Cretaceous.

The exact stage of the Upper Cretaceous represented by the Asuncion, *Glycymeris veatchii*, and Garzas faunas is not known but published reports, especially those on the saurian remains, afford considerable information on this point.

Camp[48] made a careful comparative study of the mosasaurs from the Moreno along the west side of the San Joaquin Valley and as a result named two new genera and three new species. These are *Kolposaurus bennisoni*, *K. tuckeri*, and *Plesiotylosaurus crassidens*. Regarding the age of this material Camp states (p. 26):

[46] Lois T. Martin, letter dated June 20, 1940.

[47] Personal communication. Letter dated March 8, 1943.

[48] Charles L. Camp, "California Mosasaurs," *Memoirs Univ. California*, Vol. 13, No. 1 (1942), pp. 1–68.

> *Kolposaurus* appears to be the most advanced genus yet described in the family Mosasauridae. *K. bennisoni* may be younger than any previously recorded Maestrichtian mosasaur. The top of the Upper Cretaceous sequence in central California is not easily recognized, but it is probably post-Maestrichtian in age in relation to the European section. It may be slightly below the Danian, *sensu stricto;* that is, Upper Cretaceous beds such as the Craie de Cardesse in which ammonites and belemnites are lacking. . . . The general area concerned is the exposed Upper Cretaceous along the west side of the San Joaquin Valley from Patterson south to Coalinga. Farther west, in the Santa Lucia Mountains, Dr. N. L. Taliaferro has noted great angular unconformities below what are here called the Upper Panoche beds. It would therefore seem advisable either to restrict the name "Chico" to the beds above these unconformities, or to give this upper series a new name.

Again, on page 47, Camp states:

> Two advanced species of a new genus of marine reptiles related to *Mosasaurus* appear to occur in the Upper Cretaceous of California. The species *Kolposaurus bennisoni* is more advanced in some characters than other known mosasaurs and indicates an age later than Maestrichtian for the sands in which it occurs. The species *Kolposaurus tuckeri*, associated with Maestrichtian invertebrates, is accompanied by another new genus of giant mosasaurs (*Plesiotylosaurus*) related to *Tylosaurus*.

The horizon at which *Kolposaurus bennisoni* was found is, according to Camp (p. 2): "225+ ft. above the base of the 'Garzas sand' member of the 'Moreno formation'." Garzas invertebrates occur in the vicinity. *Kolposaurus tuckeri* was found near the type section of the Moreno and is, according to the mapping of Anderson and Pack,[49] at a lower horizon in the Moreno than *K. bennisoni*. This is in agreement with Camp's opinion that *K. bennisoni* represents a more advanced evolutionary stage than *K. tuckeri*. The former is regarded as post-Maestrichtian (Danian?) and the latter as Maestrichtian. The writer is indebted to Charles L. Camp for criticizing and approving, in its present form, the foregoing statements.

This determination of the age of *K. tuckeri* is confirmed by Welles,[50] who states that the plesiosaurs from the same locality are very advanced and represent a late stage in the Cretaceous and, like the associated mosasaurs, are unquestionably Maestrichtian. According to A. S. Campbell (quoted by Welles) the associated foraminiferal faunule (*Bulimina obtusa* zone) is Maestrichtian.

Kolposaurus bennisoni definitely is associated with the Garzas fauna. The relation of *K. tuckeri* to the Garzas fauna is not known positively, since the Garzas sand dies out southward before reaching the locality. The absence of the Garzas fauna from the area in which *K. tuckeri* was found is believed to be due to change in lithologic type, sand to shale, rather than to any great difference in age. In the Santa Lucia Range the fauna is found in sandstones and not in the interbedded shales, or the shales into which the sandstones grade.

[49] Robert Anderson and Robert W. Pack, "Geology and Oil Resources of the West Border of the San Joaquin Valley North of Coalinga, California," *U. S. Geol. Survey Bull. 603* (1915).

[50] S. P. Welles, "Elasmosaurid Plesiosaurs with Description of New Material from California and Colorado," *Memoirs Univ. California*, Vol. 13, No. 3 (in press).

The foraminiferal faunule from the Santa Lucia Range, which comes from shales interbedded with sandstones containing the Garzas-Asuncion fauna, is said to be like those near the Moreno-Panoche contact; hence it should be close to the horizon at which the suarian remains were obtained.

The evidence afforded by the mosasaurs indicates that the Garzas fauna, hence the Asuncion fauna, ranges as high as the Danian, or at least to the top of the Maestrichtian, but it does not shed any light on the possible downward extension of the fauna. Since nothing definite appears to be known regarding the range of this fauna there is no direct evidence as to how far down into the Upper Cretaceous it might extend. It is quite possible that the characteristic invertebrate fossils might be relatively long range forms and there is no apparent reason why the fauna should not extend well down into the Senonian.

The only evidence as to the possible downward extension of the Asuncion fauna is the probable downward limit of *Acila* (*Truncacila*) *demesa* Finlay, Schenck and associated forms. Schenck[51] states that *Acila demessa* occurs in the type Chico formation, on Big Chico Creek, 1,250 feet above its base where it is associated with ammonites that, according to Siemon W. Muller, are Campanian (late Senonian) in age. This does not necessarily mean that *A. demessa* is confined to the Campanian. It ranges through 1,100 feet of beds in the Redding district and 750 feet in the Santa Ana Mountains[52] and may well extend into the Maestrichtian.

As far as the writer is aware the ammonite genus *Parapachydiscus*, which occurs in the Asuncion, is found only in the upper Senonian and Maestrichtian.

Nomland and Schenck[53] restudied the fossils collected by C. H. Davis at Slate's Hot Springs and collected additional material. They state that the fossil identified as *Nucula* (*Acila*) sp. by Davis appears to be *Acila demessa.* From the same locality they obtained a baculite which was sent to J. B. Reeside, Jr., who reports as follows.

> I do not see how there can be any question of the specimens representing a *Baculites* of the group of *B. anceps* Lamarck. This group, in America, seems to range from Emscherian (Santonian) up into lower Maestrichtian. So far as I know, the European range is about the same, perhaps extending a little higher than in America, into upper Maestrichtian. I do not know of its occurrence in Turonian or Cenomanian horizons.

This is additional evidence about the late Upper Cretaceous age of the upper, fossiliferous part of the Asuncion.

Although there is no positive evidence regarding the complete range in age of the Asuncion fauna, it is believed that the best available information indicates

[51] H. G. Schenck, "*Acila princeps,* a New Upper Cretaceous Pelecypod from California," *Jour. Paleon.*, Vol. 17 (1943), pp. 60–68.

[52] H. G. Schenck, *op. cit.*, p. 67, states that Popenoe's *Acila* localities indicate a range of 300 feet. Actually the range is 750 feet at a minimum as may be readily seen by consulting and comparing Popenoe's map (Fig. 2), columnar sections (Fig. 3), and check list (Fig. 4).

[53] J. O. Nomland and H. G. Schenck, "Cretaceous Beds at Slate's Hot Springs, California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 21 (1932), pp. 37–49.

that it represents the late Senonian and the Maestrichtian and probably extends into the Danian (using Danian in the sense of the latest stage in the Upper Cretaceous).

There is no direct evidence in the Santa Lucia Range about the stage or stages represented by the great thickness of unfossiliferous Upper Cretaceous sediments that lie below the upper fossiliferous zone. That they are Upper Cretaceous is shown by the fact that they rest unconformably on the Jack Creek formation which also is Upper Cretaceous. As previously stated, it is believed that the Santa Lucian orogeny occurred after the Turonian. If this is the case then the Asuncion as a whole is later than the Turonian.

CONDITIONS OF DEPOSITION

Strong cross-bedding, rapid lateral variation, predominantly coarse sediments, and great thickness are regarded as evidence of rapid deposition in shallow water in a sinking basin. A little more definite evidence about the possible depth and temperature of the water might be obtained by a consideration of the ecology of modern representatives of certain genera present.

The genus *Acila* has been studied by Schenck,[54] who states (page 33) "that the greatest number of specimens comes from temperate waters; that is, between 40° and 70° F." They have a considerable depth range but the majority appear to occur at depths of less than 150 fathoms.

Merriam,[55] who made a detailed study of turritellas states (p. 10):

> Turritella is a bottom-dwelling, creeping type of gastropod adapted to the salinities of the open ocean. So far as is known, it does not tolerate brackish water. By far the greater number of Recent species inhabit tropical waters, in which they attain maximum size, degree of ornamentation, and intensity of coloration. The number of species decreases progressively as we pass to subtropical and into temperate marine provinces. In cooler waters the European species *T. communis* Risso occurs off the coast of Norway and is reported from Iceland. This, however is exceptional. . . . Temperature data obtained with dredgings show that *T. communis* usually inhabits water with a summer bottom temperature varying from about 48° to 57° F. *T. sinuata* Reeve at Port Jackson, Australia, is reported in waters of 63° F.

As far as bottom conditions are concerned, *Turritella* does not appear to be limited as it occurs on everything from gravelly to muddy bottoms.

Regarding bathymetric limitations, Merriam states that *Turritella* is confined in large part to the upper part of the neritic zone. Of 45 occurrences, 80 per cent were found at less than 43 fathoms. Of 24 stations at which *T. communis* was dredged, the average depth is 13 fathoms. Data for 27 species show that more than 20 per cent occur at depths of 5–10 fathoms and 90 per cent at depths of less than 40 fathoms. Although the preceding data are, naturally, for living rather

[54] H. G. Schenck, "Nuclid Bivalves of the Genus *Acila*," *Geol. Soc. America Spec. Paper 4* (1936). 149 pp.

[55] Charles W. Merriam, "Fossil Turritellas from the Pacific Coast Region of North America," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 26 (1941), pp. 1–214.

than fossil species, it is the best information available and should give the approximate conditions for the Upper Cretaceous. From the character of the sediments and the fossils it appears that the Asuncion was deposited in rather shallow marine waters, largely in the open ocean, at depths probably not greater than 20 fathoms. There is greater uncertainty regarding the bottom temperature but it appears to have been somewhere between 50° and 65° F.

Practically no data are available about the prevailing climate of the land areas from which the detritus was derived. The Cretaceous is filled with carbonized plant fragments, but rarely are they well preserved; commonly they are fragmentary and give evidence of rather long transportation that resulted in almost complete maceration. According to Ralph W. Chaney (personal communication) the closest fairly large Upper Cretaceous flora is in Washington and British Columbia. This flora indicates a rather warm temperate climate with rather high seasonal rainfall and relatively frostless conditions.

A few poorly preserved plant remains were collected at Slate's Hot Springs by Fairbanks in 1893 and much later by Nomland. Those collected by Fairbanks were submitted to Fontaine, who was able to determine but one species, *Sequoia fairbanksi.*[56] The material collected by Nomland was submitted to Knowlton,[57] who stated he recognized a sequoia and two ferns. Both Fontaine and Knowlton emphasized that the material was very poorly preserved and evidently had suffered from maceration. Both regarded the meager flora as Jurassic. However, the material came from the same beds as the baculite shown to be late Upper Cretaceous by Reeside.

This small and unsatisfactory flora is not inconsistent with the climate previously mentioned.

Fragmentary plant remains are exceedingly abundant in the Cretaceous of the Coast Ranges. Although common in the Marmolejo and Jack Creek formations, they are especially abundant in the Asuncion, in places forming impure coaly layers. They are not confined to any particular lithologic type but are most conspicuous in the fine sands and silts, probably because they are partly masked by the more rapidly accumulating coarse sediments. The abundance of plant remains indicates that the land area from which the sediments were derived was, in part at least, well covered with vegetation and their fragmentary, commonly indeterminate character indicates rather long transportation in water, resulting in almost complete maceration.

RELATION OF ASUNCION TO OLDER AND YOUNGER ROCKS

As previously stated, the Asuncion rests unconformably on all older rocks, including the Jack Creek formation, of Upper Cretaceous age. There is a general northward transgression across Cretaceous and Jurassic rocks onto the ancient

[56] W. M. Fontaine, in L. F. Ward *et al.*, "Status of the Mesozoic Floras of the United States," *U. S. Geol. Survey Mon. 48*, Pt. I, pp. 147, 178–79, Pl. 45, Figs. 9–11.

[57] F. H. Knowlton, quoted by Nomland and Schenck, *op. cit.*, p. 43.

crystalline complex. In turn it is unconformably overlain by everything from the Paleocene to the Plio-Pleistocene Paso Robles gravels. The angular discordance between the Asuncion and the Paleocene is comparatively slight, but the unconformity between the Upper Cretaceous and the Miocene is, as a rule, very strong and gives evidence of important orogenic movements and deep erosion between Paleocene and Miocene. The maximum discordance occurs in the southeast part of the Adelaida Quadrangle where the Vaqueros (lower Miocene) transgresses the upturned edges of 7,000 feet of Upper Cretaceous beds in a little more than 2 miles. In many places the Cretaceous was entirely removed prior to the deposition of the Miocene, which in many places rests directly on the Franciscan, or even on the crystalline basement complex.

PROBABLE EQUIVALENTS OF JACK CREEK AND ASUNCION FORMATIONS IN ADJACENT REGIONS

The chief difficulty in definitely correlating the Upper Cretaceous units in the Santa Lucia Range with other parts of the Coast Range is the rather scanty knowledge of the faunas earlier than the one previously described. Any correlation of the Jack Creek and the lower part of the Asuncion must be based on the diastrophic history and meager paleontological evidence.

Along the east side of the Diablo Range there is a great thickness of Cretaceous sedimentary rocks that usually are divided into the Panoche and the Moreno. The contact between the two is gradational and there is considerable dispute regarding the line between them, especially at some distance from the type section of the Moreno. This division does not correspond in any way with the formations proposed by the writer and has little bearing on the subject of this paper. As previously stated, the writer regards the solution proposed by A. S. Huey as the most satisfactory. From evidence at hand at present, it is believed that Anderson and Pack's Panoche-Moreno contact transgresses time and goes lower into the section toward the northwest. The beds called Moreno on Ingram and Hospital creeks appear to include formations called Panoche at the type section of the Moreno.

The Panoche, as originally mapped, includes the late Jurassic "Knoxville" shales, and the Paskenta and Horsetown stages of the Lower Cretaceous, as well as a very thick section of Upper Cretaceous beds. In several places the Upper Cretaceous "Panoche" rests unconformably on the Horsetown. Specific localities where fossiliferous basal Upper Cretaceous conglomerates, containing Lower Cretaceous débris, rest on fossiliferous Horsetown beds are: in the east part of Sec. 17, T. 13 S., R. 10 E., 2 miles east of Ortigalita Peak, Panoche Quadrangle, where the unconformable contact is overturned and dips southwest; in the NW. $\frac{1}{4}$ of Sec. 26, T. 4 S., R. 5 E., on the south side of Hospital Canyon, Carbona Quadrangle. The first locality is shown on the writer's 1941 cross section 7. A fairly large collection of fossils was obtained at the second locality, in Hospital Canyon. These have not been studied but W. P. Popenoe (personal communication), who

made a hasty examination of the fossils, considered them to be lower Upper Cretaceous. They contain nothing suggestive of the *Glycymeris veatchii* fauna. In both localities Horsetown fossils are abundant in the shales beneath the basal conglomerate of the Upper Cretaceous. The writer regards the Jack Creek and Asuncion formations as equivalent to the sediments above this unconformity, that is, to the Upper Cretaceous part of the Panoche, as originally mapped, and the Moreno. However, the Asuncion does not correspond with the Moreno alone but with the Moreno (including such tentative members as the Garzas and Volta sands) and with a considerable thickness of the underlying part of the Panoche. The Jack Creek formation is regarded as equivalent to a part, if not all, of the lower shaly phase of the "Panoche" (restricted Upper Cretaceous part). There does not appear to be any definite break within the Panoche between Hospital Canyon and Little Panoche Creek but there are lenses of coarse cobble and boulder conglomerates containing fossiliferous blocks of Upper Cretaceous sandstone and limestone. The fossils are said to be Turonian and Cenomanian. As previously stated, these conglomerates, although they do not occur everywhere at exactly the same horizon, are regarded as a local manifestation of the Santa Lucian orogeny, which separates the Jack Creek and Asuncion formations in the Santa Lucia Range. The sediments below these conglomerates, which range up to 8,000 feet in thickness, are prevailingly silty; those above, as far as the Moreno contact, contain many zones of coarse arkosic sandstones similar to the Asuncion.

In the Mount Diablo region, at the north end of the Diablo Range, Taff[58] reports an unconformity between the "Chico" and "Panoche." He states (p. 1088):

> In middle Upper Cretaceous time the sea receded westward, exposing Chico sediments. The regionally uplifted strata were broadly warped and eroded. Evidence of this is found in the basal conglomerate of the Panoche formation in the vicinity of Mount Diablo and throughout the east side of Mount Hamilton area. . . . This conglomerate, wherever found, is composed of hard, well-worn pebbles and cobbles of quartzite, quartz, granitic and basic porphyritic rocks, together with partially worn and angular boulders of sandstone and limestone containing characteristic Chico fossils.

Taff describes the Chico (lower part of the Upper Cretaceous) as being made up of a thin basal conglomerate overlain by 7,000 feet of shale, impure limestone, and thin sandstones. The Panoche is described as composed of a basal conglomerate and about 5,000 feet of arkose sandstone and sandy shales. The Panoche, as everywhere, grades upward into the Moreno, 7,000 feet thick and largely shale. Aside from the fact that there are no sediments lithologically similar to the Moreno in the Santa Lucia Range these divisions correspond both in stratigraphic position and predominant lithologic types with the divisions of the Upper Cretaceous in the Santa Lucia Range. The writer regards the beds described as "Chico" by Taff as being equivalent to the Jack Creek and the "Panoche" and "Moreno" of the same author as equivalent to the Asuncion. There seems little

[58] J. A. Taff, "Geology of Mount Diablo and Vicinity," *Bull. Geol. Soc. America*, Vol. 46 (1935), pp. 1079–1100.

doubt that Taff's "middle Upper Cretaceous" unconformity is the result of the same force that produced the Santa Lucian orogeny.

There is less certainty regarding correlatives of the Jack Creek and Asuncion formations in the southern end of the Diablo Range and in the Castle Mountain Range, but there is good evidence for the Santa Lucian orogeny, evidence that already has been presented. The crest of Castle Mountain Range is made up in part of coarse arkose sandstones of late Upper Cretaceous age, resting on Lower Cretaceous and Franciscan-Knoxville rocks. East of this range there is a thick section of Cretaceous sediments below the Eocene. Fossils were collected by Dr. Ralph Stewart from near the top of this Cretaceous section on Arroyo Pinoso and studied by Popenoe. Regarding these fossils (from field locality 128) Popenoe states:[59]

> I place field locality 128 as fairly early Upper Cretaceous, earlier than anything at Chico Creek and approximately of the same age as Packard's *Actaeonella oviformis* zone in the Santa Ana Mountains, possibly Cenomanian.

The writer regards the coarse arkose sandstones along the crest of Castle Mountain Range as equivalent to the Asuncion and the Upper Cretaceous beds along the Arroyo Pinoso, containing early Upper Cretaceous fossils, as the probable equivalents of the Jack Creek.

It is believed that the Santa Lucian orogeny affected most of the Coast Ranges south of San Francisco Bay, but to varying degrees. Uplift and erosion took place in the midst of the Upper Cretaceous over most of the region, but the sea was not completely withdrawn from some localities. However, even in such areas the disturbance caused an influx of coarse sediments. Beds equivalent, in whole or in part, to the Jack Creek and Asuncion formations are believed to be widespread over the area. No evidence of the Santa Lucian orogeny has been observed in the north Coast Ranges and, as far as the writer is aware, there are no unconformities in the midst of the Upper Cretaceous in that region.

DIP CREEK FORMATION—PALEOCENE

DISTRIBUTION

Sediments of Paleocene age have been found in only two general districts in the Santa Lucia Range. Although they are insignificant in area they afford important information regarding the close of the Cretaceous and aid in dating the early Tertiary diastrophism.

There are two small areas of Paleocene sediments in the north part of the Adelaida Quadrangle and one in the Lucia Quadrangle, 50 miles northwest. The two areas in the Adelaida Quadrangle lie on the flanks of an anticline that brings the Asuncion from beneath the Miocene. The largest of these areas lies along either side of Dip Creek and rests unconformably on the Godfrey Flat shale phase of the Asuncion; on the southwest it is bounded by the Kavanaugh thrust and

[59] W. P. Popenoe, letter dated April 28, 1941.

on the south it is unconformably overlain by lower Miocene (or Oligocene) redbeds. The Paleocene beds strike N. 70° E. and dip 20° S. The other area forms a long narrow strip, 4 miles long and 500–800 feet wide, that extends northwest from Chimney Rock on San Marcos Creek. This narrow strip rests on Asuncion shales and sandstones on the northeast flank of the anticline and is unconformably overlain by redbeds and Vaqueros sandstone on the northeast. The strike is northwest and the dip 60°–70° NE. The two exposures in the Adelaida Quadrangle have a combined area of about 2 square miles.

Reiche[60] reports the presence of fossiliferous Paleocene sedimentary formations in the Lucia Quadrangle, where they occur, near the crest of the range, in the trough of a faulted syncline in the Asuncion. Here the beds are only about 200 feet thick and have an outcrop area of a little more than a square mile.

In the Adelaida Quadrangle the Paleocene sedimentary rocks rest unconformably on the Asuncion with a thick basal conglomerate that contains abundant débris of the underlying Cretaceous. Reiche states that, in the Lucia Quadrangle, the Paleocene beds rest conformably on the Cretaceous and that the contact was arbitrarily placed 100 feet below the only fossil horizon. The writer has not visited the locality in the Lucia Quadrangle.

TYPE SECTION OF DIP CREEK FORMATION

The best section in the Adelaida Quadrangle occurs along Dip Creek, in the west part of Sec. 30, T. 25 S., R. 10 E., where 1,320 feet of beds are continuously exposed. This has been chosen as the type section. For many years the name Martinez has been given to practically all of the earliest Eocene sedimentary beds in the state and the name has become practically synonomous with Paleocene. The type section is exposed on the southwest limb of the Pacheco syncline, south of the town of Martinez, Contra Costa County, California. However, it has been shown[61] that the type section of the Martinez, as originally defined and as mapped by Lawson[62] in the Concord Quadrangle, contains beds not only of Paleocene but of lower and middle Eocene age as well. Since no fossils that would indicate a later age than the Paleocene have been found in the Dip Creek section, and since the Martinez at the type section contains later Eocene sediments, it is believed advisable to give a local formational name rather than to use the name Martinez. The name Dip Creek formation is proposed for the Paleocene beds in the central and south Santa Lucia Range.

LITHOLOGIC CHARACTER AND THICKNESS

The Dip Creek formation is so similar lithologically to the Asuncion that, if fossils had not been found in the basal beds, they would have been mapped as a

[60] Parry Reiche, "Geology of the Lucia Quadrangle," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 24 (1937), p. 144.

[61] Elizabeth A. Watson, "Age of the Martinez Formation of Pacheco Syncline, Contra Costa County, California," *Amer. Midland Naturalist*, Vol. 28 (1942), pp. 451–56.

[62] Andrew C. Lawson, "San Francisco, California," *U. S. Geol. Survey Geol. Atlas Folio 193* (1915).

late Cretaceous unit resting with slight unconformity on the Asuncion. They contain the same type of coarse cobble and boulder conglomerates and the same type of coarse to fine-grained arkose sandstones, commonly filled with carbonized plant remains. To complicate further the problem the faunas are so closely related that poor collections from the Asuncion almost invariably have been called "Martinez." Both the lithologic character and the fauna are so similar that it required 8 field seasons, and greatly enlarged maps and airplane pictures, to separate the two satisfactorily.

The only notable difference between the Dip Creek and the Asuncion is in the basal conglomerate which everywhere contains abundant débris of the underlying Upper Cretaceous. Fragments of limestone nodules and lenses, derived from the Asuncion shales, are especially common and large angular to subangular blocks of Asuncion sandstones are numerous. The print of a Cretaceous ammonite was found in a block of Asuncion sandstone in a conglomerate, at the type section, about 150 feet above the base of the Dip Creek formation. Aside from blocks and fragments of the Cretaceous the constituents of the conglomerates have the same size, degree of rounding and character found in the Asuncion conglomerates; well rounded pebbles, cobbles, and boulders of the old crystalline complex are the most abundant materials.

The writer is greatly indebted to C. E. Van Gundy for mineral and mechanical analyses of 9 sandstones from base to top along the type section and for a careful measurement of the thickness. The following account of the sandstones and the thickness is taken from Van Gundy.[63]

Table III shows the range and the average mineral content of 9 sandstones, all from the type section. This table shows the great similarity between the Dip Creek and Asuncion sandstones. The first 4 mineral analyses shown in Table II are of Asuncion sandstones in the same general area as the mineral analyses of Dip Creek sandstones shown in Table III; hence, they are directly comparable.

The most noteworthy difference between the Asuncion and Dip Creek sandstones, from the same area, is the presence of characteristic Franciscan minerals in the latter. Such minerals as actinolite, chromite, crossite, glaucophane, picotite, and rutile appear in the Paleocene sandstones and clearly indicate that Franciscan areas were exposed, probably toward the west, during the Paleocene. Franciscan areas also were exposed during the deposition of the Jack Creek and Asuncion, but notable amounts of Franciscan débris do not appear in the belt represented by Table II. The writer concludes that the uplift at the close of the Cretaceous somewhat restricted the extent of the sea and brought up areas of Franciscan not far west of the present outcrops of the Dip Creek formation.

According to Van Gundy, who made mineral analyses of both the Upper Cretaceous and Paleocene from the same region, many of the heavy-mineral grains

[63] C. E. Van Gundy, "The Relations of the Upper Cretaceous and Martinez Formation in the Northern Part of the Adelaida Quadrangle, California," *unpublished Master's thesis*, Department of Geological Sciences, University of California, Berkeley, University Library.

of the Paleocene show better rounding than those in the Upper Cretaceous. This is especially true of the garnets which are more abundant in the Dip Creek formation. This fact, together with the presence of abundant pebbles, cobbles and

TABLE III

Mineral Analyses of 9 Sandstones from Type Section of Dip Creek Formation, Adelaida Quadrangle*

Light Separates Computed to 100 Per Cent	*Range*	*Average*
Quartz	47.0–70.1	59.9
Feldspar (total)	22.1–41.0	32.0
(Microcline)	(0 – 4.6)	(2.2)
(Orthoclase)	(13.2–25.8)	(19.7)
(Albite)	(2.1– 5.8)	(3.7)
(Andesine)	(0 – 4.4)	(0.7)
Muscovite	0 – 4.4	0.8
Rock fragments	3.7–16.8	7.3
Heavy Separates Computed to 100 Per Cent		
Actinolite	0 –P	P
Allanite	0 –P	P
Apatite	0 – 3.3	0.4
Biotite	2.4–20.7	6.3
Chlorite	P– 6.9	2.1
Chromite-picotite	0 – 1.2	P
Crossite	0 –P	P
Epidote	0 – 4.0	0.5
Garnet		
Colorless	1.5–12.9	4.5
Pink	2.8–11.5	6.1
Amber	0 – 3.5	1.1
Brown	0 – 2.8	0.4
Glaucophane	0 –P	P
Hornblende	0 – 4	0.6
Ilmenite	0.5–10.0	4.0
Magnetite	1.5–41.3	8.5
Rutile	0 –P	P
Sphene	2.5–13.6	8.3
Tourmaline	P– 3.3	0.5
Zircon	P–12.3	3.2
Rock fragments†	29.6–60	51.8

* Analyses by C. E. Van Gundy.
† Rock fragments include myrmekite and leucoxene.
P = present.

boulders of the Asuncion in the conglomerates, indicates reworking of the underlying Upper Cretaceous.

The following section along Dip Creek, was measured by Van Gundy.

	Thickness in Feet
Vaqueros formation	
Unconformity	
Dip Creek formation	
Thin-bedded, well sorted, fine-grained sandstone	600
Massive conglomerate containing lenses of sandstone	60
Medium- to fine-grained sandstone	490
Massive basal conglomerate, highly fossiliferous. Contains lenses of sandstone	170
Total	1,320
Unconformity	
Upper Cretaceous	

Only the lower 500 feet of conglomerate and sandstone is exposed in the narrow belt extending northwest from Chimney Rock, the upper part having been removed before the deposition of the land-laid redbeds and Vaqueros.

All that has been said regarding the depth of deposition and the climatic conditions of the Asuncion applies with equal force to the Dip Creek formation.

FAUNA OF DIP CREEK FORMATION

Large fossil collections have been made, especially along Dip Creek and on the northwest but none has been systematically studied. The most abundant fossils are various species of *Turritella* and a heavy-shelled *Glycymeris* that appears to be almost identical with *G. veatchii* in the Asuncion. The Turritellas have been studied by Merriam who reports the following species and subspecies: *Turritella pachecoensis* Stanton sub sp. *adelaidana* Merriam; *T. chaneyi* Merriam; *T. pachecoensis* Stanton, and *T. infragranulata* Gabb. All these, except *T. chaneyi* which also occurs in the Upper Cretaceous, are found only in the "Martinez," that is the lowermost Eocene.

The writer is indebted to B. L. Clark, H. G. Schenck, C. W. Merriam and Miss A. Myra Keen for the following list.

Amaurellina sp.
Cucullaea mathewsonii Gabb
Glycymeris veatchii, var.
Lyria hannibali Waring
Polinices hornii Gabb
Tornatella pinguis Gabb
Trachytriton titan Waring
Turritella chaneyi Merriam
Turritella infragranulata Gabb
Turritella pachecoensis Stanton
Turritella pachecoensis Stanton sub sp. *adelaidana* Merriam
Venericardia venturaensis Waring

This is only a partial list as there are others that have not been determined.

Although this is a comparatively short list it is believed that there are a sufficient number of characteristic species present to assign the beds to the "Martinez stage," using this term as ordinarily employed in California, as synonomous with the lowermost Eocene.

The only species definitely determined as being common to both the Asuncion and Dip Creek formations is *Turritella chaneyi*. However, the faunas are so similar that they have been confused frequently. Good and abundant material, or the presence of ammonites or baculites, are necessary to differentiate them.

RELATION TO OLDER AND YOUNGER FORMATIONS

The Dip Creek formation everywhere rests on the Asuncion in the Santa Lucia Range; it has not been found resting on any of the older rocks. This fact, together with the marked similarity in fauna and lithologic character appears to indicate that an important diastrophism did not take place between the late Upper Cretaceous and the Paleocene. This is in accord with observations in other parts of the Coast Ranges; in many places it is difficult to establish the exact contact between them.

That there was uplift at the close of the Cretaceous in the south part of the

Santa Lucia Range is shown by the fact that the Dip Creek formation contains abundant débris of the Asuncion and also rests on different beds. However, the angular discordance is slight. The writer[64] has stated that the Asuncion, in the north part of the Adelaida Quadrangle, was tilted 9° SW. and that 2,500 feet of beds were removed locally before the deposition of the Dip Creek. Subsequent work and the discovery of ammonites in beds previously regarded as Paleocene indicate that the tilt was not more than 4° or 5° and that less than 1,000 feet of beds were removed. The diastrophism at the close of the Cretaceous was not comparable in severity with the diastrophism, or diastrophisms, that occurred between the Paleocene and the lower Miocene. This is clearly shown in the northeast part of the Adelaida Quadrangle. On the southwest side of the San Marcos fault the lower Miocene rests on and transgresses several thousand feet of Asuncion and Dip Creek beds that dip northeast at a high angle toward the fault. On the northeast side of the same fault the lower Miocene rests directly on granodiorite and schist. Thus, there was profound faulting and deep erosion after the deposition of the Paleocene and before the deposition of the lower Miocene. There were local uplifts at the close of the Cretaceous but the sea does not appear to have been completely withdrawn over much of the Coast Ranges. The great geosyncline in which the Cretaceous was deposited was disturbed and modified at the close of the Cretaceous but was not completely destroyed until sometime after the Paleocene. Evidence for this statement is, of course, found chiefly in areas outside of the Santa Lucia Range.

The Dip Creek formation is unconformably overlain by pre-Vaqueros land-laid redbeds and by marine Vaqueros sandstones.

PALEOGEOGRAPHIC MAP

A paleogeographic map showing the writer's concept of the extent of the sea in California at or near the close of the Cretaceous is presented in Figure 18. Naturally, as with the case of all such maps, it is based on many assumptions and, here and there, on very scanty evidence. Several similar maps have been presented, notable among which are those by Reed[65] and Schenck.[66] The map presented here differs chiefly from Reed's map in the omission of the hypothetical land mass of Salinia and in the greater eastern extent of the sea in the vicinity of Fresno in the San Joaquin Valley. Reed's map shows the east border of the sea to be about 20 miles west of Fresno. Macdonald[67] reports the presence of fully 400 feet of Upper Cretaceous sandstones, containing *Glycymeris* and *Turritella*, in a well near Friant, 15 miles northeast of Fresno.

[64] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *California State Bur. Mines Bull. 118*, Pt. 2 (1941), p. 135.

[65] R. D. Reed, *Geology of California*, Amer. Assoc. Petrol. Geol. (1933), Fig. 20, p. 116.

[66] H. G. Schenck, "Nuculid Bivalves of Genus *Acila*," *Geol. Soc. America Spec. Paper 4* (1936), superimposed on frontispiece.

[67] Gordon A. Macdonald, "Geology of the Western Sierra Nevada between the Kings and San Joaquin Rivers, California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 26 (1941), pp. 259–60.

The paleogeographic map (Fig. 18) differs from both Reed's and Schenck's maps in north California; both earlier maps show a wide extent of Upper Cretaceous sea through "Lassen Strait" into northeast California. Schenck even shows the sea extending into northwest Nevada. There is no evidence that any

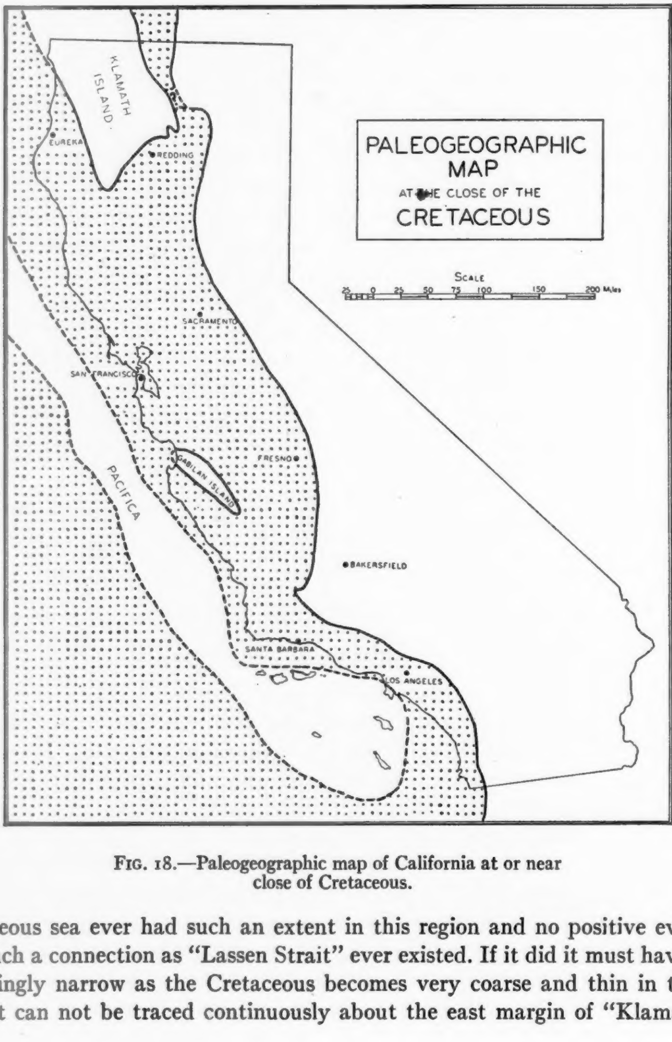

FIG. 18.—Paleogeographic map of California at or near close of Cretaceous.

Cretaceous sea ever had such an extent in this region and no positive evidence that such a connection as "Lassen Strait" ever existed. If it did it must have been exceedingly narrow as the Cretaceous becomes very coarse and thin in this region; it can not be traced continuously about the east margin of "Klamath Island."

SUMMARY AND CONCLUSIONS

Sediments of Cretaceous age are widespread in the Santa Lucia Range where they are readily divisable into three formations, each separated by profound unconformities. The Lower Cretaceous, the Marmolejo formation, occurs only in the south part of the range, and is made up of 4,000–5,000 feet of dark shales, with thin lenses of sandstone and conglomerate. West of the crest of the range, in the Adelaida Quadrangle, there are thick and very coarse basal breccias, largely made up of material derived from the Franciscan. These occur along the Las Tablas fault and thin in a short distance southwest away from the fault, indicating that there was movement, either of sharp folding or faulting, along this zone in the very late Jurassic or early Cretaceous. There is evidence for movements at this time throughout the area of the state; this period of diastrophism is called the Diablan orogeny by the writer.

The Marmolejo is identical with the lower part of the Lower Cretaceous throughout the Coast Ranges faunally and lithologically. Because of subsequent diastrophisms and deep erosion it has been removed from most of the region, but it is believed that the Lower Cretaceous sea covered practically all of the Coast Ranges.

The meager fauna of the Marmolejo formation indicates that it represents the Paskenta stage of the Lower Cretaceous; the Horsetown stage does not appear to be represented.

The Marmolejo formation was strongly folded and faulted and largely removed prior to the deposition of the Upper Cretaceous; it was only preserved in exceptionally deep synclines. The diastrophism between the Lower and Upper Cretaceous is named the mid-Cretaceous disturbance; it was state-wide but appears to have been especially severe in the Santa Lucia Range.

The earliest Upper Cretaceous, the Jack Creek formation, is made up chiefly of shales and silts with minor amounts of sandstone and shale matrix conglomerates. The lack of any but a very thin basal conglomerate and the predominantly fine-grained character of the formation as a whole indicate that the sea in which it was deposited spread quietly over a region of low relief. The Jack Creek rests only on earlier Mesozoic rocks and, as far as is known, nowhere transgresses these onto the ancient crystalline basement. The meager fauna has not been studied in detail, but it is known to be Upper Cretaceous; it is thought to represent the Cenomanian and Turonian stages.

After the deposition of the Jack Creek shales there was a profound diastrophism that was particularly severe in the Santa Lucia Range but which appears to have affected most of the Coast Ranges south of San Francisco Bay. This is called the Santa Lucian orogeny; from evidence in the Diablo Range it is believed to have taken place late in or after the Turonian. The importance of this orogeny has not been generally recognized. It exerted a profound effect on the subsequent history of the Coast Ranges through the widespread removal of earlier Mesozoic

sediments. It also appears to have had a marked effect in the localization of Eocene faulting. Although this orogeny was the strongest single interruption to deposition in the great Mesozoic geosyncline that began with the earliest Franciscan, probably in the Portlandian, it did not destroy this basin of deposition that played such an important part in the history of the Coast Ranges. However, the movements that occurred at this time had an important bearing on the Eocene movements that finally completely fragmented the Mesozoic geosyncline.

As with other diastrophisms in California, the Santa Lucian orogeny appears to have occupied but a relatively short space of time, when compared with the time required for sedimentation, and to have quickly run its course. Although the Upper Cretaceous sea was withdrawn from much of the Coast Ranges and there was deep erosion and widespread stripping, subsidence again took place, and the sea spread rather rapidly over an area of considerable relief. The latest Upper Cretaceous, the Asuncion, is the most widespread Cretaceous unit in the Santa Lucia Range, as equivalent beds appear to be in the Coast Ranges in general. The Asuncion is predominantly coarse-grained, being made up of arkose sandstone and coarse conglomerates. There is a definite increase in fine sediments toward the east, in the south part of the range, indicating derivation from the west. The relative proportion of Franciscan débris increases toward the west in the south part of the range. Near the present coast the basal conglomerates contain large angular to subrounded blocks of Franciscan chert, basalt, diabase, and sandstone as well as the typical well rounded pebbles, cobbles, and boulders of the ancient crystalline complex (Sur series and Santa Lucia granodiorite).

The Asuncion is the most fossiliferous of all the Cretaceous units, but determinable fossils have been found only in the upper part. The fauna that occurs in the upper 1,500–2,500 feet is correlated with the Garzas fauna of the west side of the San Joaquin Valley north of Coalinga and with the *Glycymeris veatchii* fauna of the Santa Ana Mountains. Although the range of this fauna is not known definitely, it is believed that there is evidence that it ranges from the upper part of the Senonian, through the Maestrichtian into the Danian. The chief evidence for its upper limit is the advanced stage of evolution of the saurian remains. The Asuncion as a whole is thought to be later than the Turonian.

The Cretaceous was brought to a close by relatively mild disturbances, as shown by the relation of the lowermost Eocene, the Dip Creek formation, which rests on the late Upper Cretaceous with relatively slight angular discordance. The Dip Creek formation is regarded as the local representative of the restricted Martinez, the lowermost Eocene. It is identical lithologically with the Asuncion and contains a fauna, that as far as genera are concerned, is very similar. It appears to have been deposited under identical conditions, shallow marine waters of less than 40 fathoms with a bottom temperature of about 50°–65°F. Like the Cretaceous as a whole the Dip Creek beds were derived from a well wooded land mass.

The conglomerates, especially those near the base, contain débris of the under-

lying Asuncion yet the angular discordance is slight, not more than 5°, and is not comparable with the discordance between the Paleocene (and late Upper Cretaceous) and lower Miocene (or older) sediments.

In summary, it may be stated that the most important results, from the point of view of the history of the Coast Ranges, brought out by a study of the Cretaceous and Paleocene of the Santa Lucia Range are thought to be as follows: (1) the marked unconformity and deep erosion between the Lower and Upper Cretaceous, (2) low relief of the surface over which the earliest Upper Cretaceous sea spread, (3) marked diastrophism and widespread stripping in the midst of the Upper Cretaceous (Santa Lucian orogeny), (4) marked difference in general grain size between the fine-grained early Upper Cretaceous and the coarse-grained late Upper Cretaceous, (5) marked relief of the surface over which the late Upper Cretaceous sea transgressed, (6) widespread distribution of the late Upper Cretaceous and the correlation of the fauna in the upper part with other faunas in California, (7) lithologic similarity of the Paleocene with the late Upper Cretaceous and the close relation between them, and (8) the fact that the break between the late Upper Cretaceous and the Paleocene is small as compared with that between the Paleocene and the lower Miocene (or earlier) sediments. The latter relation indicates that Eocene diastrophism (or diastrophisms) was very severe and played an important part in the evolution of the Coast Ranges.

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CORRELATION OF THE PECAN GAP, WOLFE CITY, AND ANNONA FORMATIONS IN EAST TEXAS[1]

JOHN T. ROUSE[2]
Wichita, Kansas

ABSTRACT

The Pecan Gap chalk of East Texas has been correlated, in previous publications,[3] with the Annona chalk of northeastern Texas and southern Arkansas. Detailed surface mapping of a belt of Cretaceous rocks in eastern and northeastern Texas shows that the Pecan Gap chalk thins and disappears north and east and that the Wolfe City sand, which underlies the Pecan Gap chalk, is to be correlated with the Annona chalk.

INTRODUCTION AND ACKNOWLEDGMENTS

It is the writer's purpose to describe the stratigraphy of the Pecan Gap chalk and the Wolfe City sand, along their belts of outcrop in East Texas from Collin County eastward into Red River County, and to discuss the correlation of these formations with the Annona chalk in Red River County, Texas. These formations belong to the Taylor group of the Upper Cretaceous.

- Upper Cretaceous
  - Gulf series
    - Navarro group
    - Taylor group
      - Upper Taylor marl (Marlbrook?)
      - Pecan Gap chalk
      - Wolfe City sand
      - Lower Taylor marl

Figure 1 shows the general location of outcrops and sections discussed. It is hoped that this paper may be of use in guiding interested parties to the sections described. Each section described is preceded by detailed instructions for finding it.

The writer desires to thank S. A. Thompson and the Magnolia Petroleum Company for permission to publish this material. The work was done under the immediate supervision of C. I. Alexander, and to both him and Mr. Thompson the writer is greatly indebted for most profitable discussion in connection with the field work and preparation of the manuscript. The micro-fossils of all the formations described have been examined by Mr. Alexander and he has confirmed the ages assigned to them.

The Pecan Gap and Wolfe City formations have been mapped from Ellis County northward and eastward to Red River County but as the outcrops south of Collin County do not have any bearing on the correlations here presented they are not described.

[1] Manuscript received, September 11, 1943.

[2] Geologist, Magnolia Petroleum Company.

[3] L. W. Stephenson, "A Contribution to the Geology of Northeastern Texas and Southern Oklahoma," *U. S. Geol. Survey Prof. Paper 120* (1918), pp. 129–163.

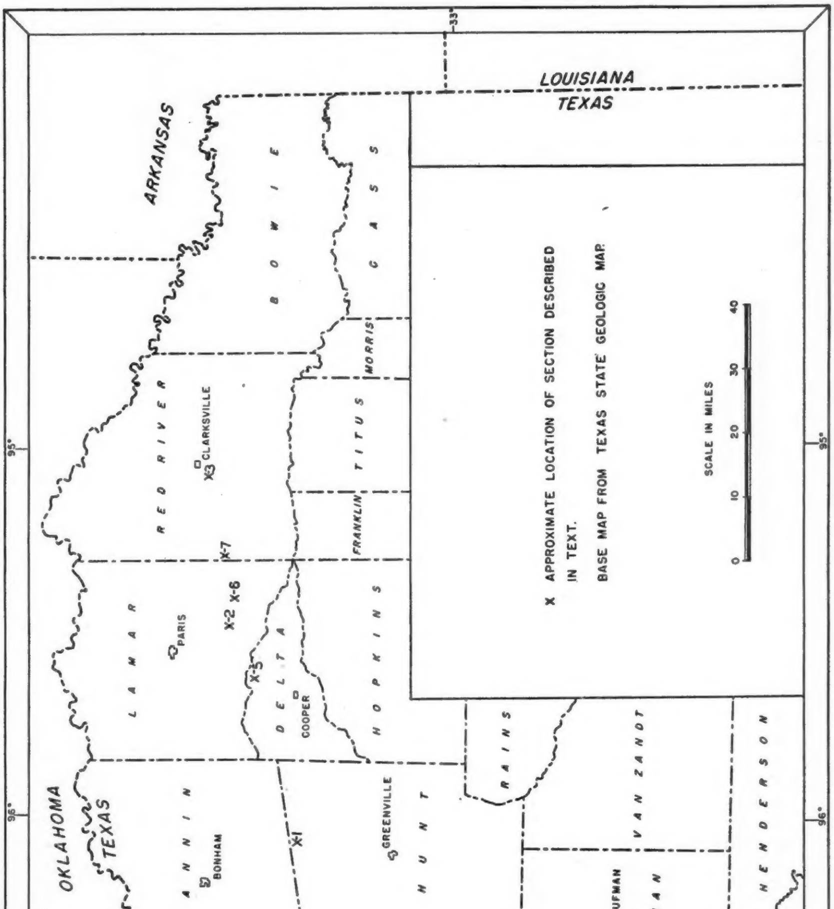


FIG. 1.—Index map of northeastern Texas showing approximate locations of sections described in detail.

WOLFE CITY

The Wolfe City formation (named by Stephenson[4]) with the type locality near Wolfe City, Hunt County (Location 1, Fig. 1), shows greater lithologic variation in short distances along the strike than other formations described in this paper. The original name, "Wolfe City sand," is confusing, as in many localities the formation is arenaceous clay, marl, or sandy chalk rather than sand. The sandy facies of the Wolfe City formation is best developed in the vicinity of the town of Wolfe City. The formation varies in thickness from 200 to 300 feet.

North of Farmersville, Collin County, where the strike of the Cretaceous beds changes from north to northeast, the Wolfe City, immediately beneath the Pecan Gap, is calcareous sand, the upper part of which contains a great abundance of *Exogyra ponderosa.* This sandy facies of the Wolfe City, approximately 130 feet thick, abounds in hard, calcareous concretionary ledges, many of which are fossiliferous. Beneath this sand, 165 feet of sandy clays are found, and here the total thickness of the Wolfe City is 295 feet.

In southern Lamar County and northern Delta County the upper part of the Wolfe City is chalky sand. The character of the lower part of the section is not known as it is covered with alluvium. South of Bairdstown and east toward Minton (Lamar County) excellent exposures of the chalky facies of the upper Wolfe City are found. In an old quarry southeast of Bairdstown (Lamar County) the following section of the Pecan Gap and Wolfe City is exposed.

Location 2, Fig. 1. From Bairdstown, south 0.6 mile; east 0.3 mile; south 0.1 mile; east 0.2 mile; south 0.4 mile; east 1.1 miles; south 0.6 mile; west 0.1 mile; south 0.5 mile; east 0.1 mile; south 0.1 mile; east 0.25 mile; turn north on farm road 0.2 mile to quarry; R. M. Robinson tract, Isaac Cruse Survey.

	Thickness in Feet	
Pecan Gap	3	(3) White chalk with abundant phosphate pebbles and phosphatized fossil casts at base
Wolfe City	5	(2) Tan to white sandy chalk
	4	(1) Brown argillaceous sand with abundant *Exogyra ponderosa*

East from this quarry into Red River County the upper Wolfe City continues to become more chalky. The geologic map of Texas[5] terminates the Wolfe City near Deport (eastern Lamar County) but field work has shown that the chalky facies of this formation continues into western Red River County and in the W.P.A. quarry, 2½ miles east of Fulbright on the Clarksville road, the Wolfe City has become slightly arenaceous chalk, lithologically indistinguishable from the Annona chalk near Clarksville.

ANNONA CHALK

Outcrops of the Annona chalk are confined to the northeastern part of the area mapped in Red River and Bowie counties. Exposures of this chalk are

[4] *Ibid.*, p. 155.

[5] *Univ. Texas Bur. Econ. Geol. Bull. 3232.*

very numerous, especially in the vicinity of Clarksville. The Annona is white, generally well bedded and jointed, hard, massive fossiliferous chalk. Field work was not carried north to the base of this chalk but information from core drilling in western Red River County south of Fulbright shows that this formation is 300–400 feet thick. Samples from these core-drill holes show that the Annona is characterized by an upper chalk, locally slightly sandy, underlain by marly shales containing chalk lenses. Beneath the Annona is the Brownstown formation. About 3½ miles southwest of Clarksville and ½ mile east of McCoy (Location 3, Fig. 1), the top of the Annona contains a great abundance of *Exogyra ponderosa*. In the area mapped west of the Annona outcrops, *Exogyra ponderosa* has been found in great abundance in the Wolfe City, both in the sandy and chalky facies, but not in the Pecan Gap.

PECAN GAP

The Pecan Gap chalk was named by Stephenson,[6] its type locality being near the town of Pecan Gap, Delta County. As a chalk the Pecan Gap is best represented in Collin, Hunt, Fannin, and Lamar counties. South of Collin County, the Pecan Gap changes to chalky marl, the top of which is difficult to differentiate from the overlying upper Taylor marls. East of Lamar County, the Pecan Gap thins within a short distance and disappears. Its thickness varies from less than one foot in western Red River County to 120 feet in Hunt County. The base of the Pecan Gap in North Texas is easy to recognize as it is characterized by a zone, varying from several inches to several feet in thickness, of phosphate pebbles, phosphatized fossils, and glauconite. This basal phosphate zone has been traced north and east from northern Rockwall County to western Red River County.

North of Copeville and southwest of Farmersville, Collin County, the entire Pecan Gap section is hard white chalk and bluish limestone. Exposures of this facies are abundant in the steep east slopes of Pilot Creek, west and south of Farmersville. The basal contact zone of the Pecan Gap here has characteristics that continue north and east into Red River County where the chalk disappears. In addition to the black phosphate pebbles, the basal zone contains an abundance of phosphatized *Baculites*, gastropods, and internal molds of pelecypods, and in many exposures this zone is rich in glauconite. This zone stands out on weathered slopes and can be recognized readily in plowed fields as the pebbles and fossils generally appear as a gravel-like streak through the field.

At all good exposures of the contact, chalk-filled borings extend down into the underlying Wolfe City formation. A striking feature of the basal contact zone is its marked change in thickness in a short lateral distance. This is best shown in two sections west of Farmersville. The first is a composite section in the two W.P.A. quarries west of Farmersville.

Location 4, Fig. 1. From public square in Farmersville west on old Farmersville-McKinney road 1.6 miles; north 0.2 mile; northwest 0.3 mile; north 0.1 mile; west 0.5 mile to secondary road north through gate to W.P.A. quarry; north 0.6 mile to quarry.

[6] L. W. Stephenson, *op. cit.*, p. 156.

	Thickness in Feet—Inches			
Pecan Gap	8		(9)	Hard arenaceous, crystalline, blue gray limestone. Thin wavy laminations and cross-bedding. Some glauconite and here and there a phosphate pebble
	4		(8)	Mottled blue to greenish blue and gray arenaceous glauconitic, crystalline limestone and abundant fucoids
	8		(7)	Same as 9 above (3-foot break between quarries)
	2	9	(6)	Hard gray to brown arenaceous crystalline limestone. Fine laminations and cross-bedding. Small nests of glauconite
	15	10	(5)	Soft, blue, glauconitic arenaceous limestone; some small pelecypods
	3		(4)	Hard, blue glauconitic limestone
	1		(3)	Conglomerate, black phosphate pebbles and phosphatized fossils, especially *Baculites*. Some shark teeth and nests of pyrite. Dark green glauconitic sandy calcareous matrix
	0	1	(2)	Glauconitic calcareous sand with smaller quantities of pebbles than above. Some bone fragments
	4	6	(1)	Extremely coarse conglomerate—sandy glauconitic matrix is subordinate. Phosphate and limestone pebbles and some pyrite, abundant fossils, especially *Baculites*. Some teeth and bones

Base of quarry floor—Superintendent reported soft clay below No. 1.

In the second, on the old Farmersville-McKinney road, 0.6 mile south of the foregoing quarry section, the basal Pecan Gap has a very different appearance, as shown in the following section.

	Thickness in Feet—Inches			
Pecan Gap	3		(3)	Soft terra cotta chalk alternating with layers of hard arenaceous limestone
		2	(2)	Basal zone. Black phosphate pebbles and phosphatized *Baculites*
Wolfe City	5		(1)	Black arenaceous clays with abundant nacreous fossils and some hard, round limestone concretions

From Farmersville north and east the Pecan Gap continues as moderately hard, well bedded chalk through Hunt, Fannin, Delta, and Lamar counties.

In Delta County the top of the Pecan Gap formation is well exposed. The best exposure showing the upper Taylor marls, Pecan Gap, and Wolfe City in continuous section is $2\frac{1}{2}$ miles north of Enloe in northeastern Delta County.

Location 5, Fig. 1. From Enloe east 0.7 mile; north 1.5 miles; west 0.25 mile; north 0.7 mile; west 0.1 mile on old quarry road; walk east 0.2 mile to large creek and exposures. J. A. Jackson tract, S. Turner Survey.

	Thickness in Feet		
Upper Taylor marls	4	(3)	Soft white to cream chalky marls. Basal 2 inches, conglomerate zone in which the pebbles are dominantly limestone, many of which have very irregular shape and greenish yellow stain on exteriors. Some pelecypods and a few *Baculites*, but no coiled snails or black phosphate pebbles like those found in basal Pecan Gap conglomerate zone
Pecan Gap	25	(2)	Hard massive, fairly well bedded white chalk. Base of chalk marked by 6-inch conglomerate zone of phosphate pebbles and phosphatized fossils together with glauconite as in previously described sections
Wolfe City	6	(1)	Soft, fossiliferous sands with abundant chalk stringers and chalk-filled borings

In eastern Lamar County, the Pecan Gap has thinned to 5 feet. This is shown in an exposure north of Milton.

Location 6, Fig. 1. From Milton north 0.6 mile; west 0.1 mile; north 0.6 mile to exposure. R. C. Harvey tract, Joseph Deck Survey.

	Thickness in Feet—Inches		
Upper Taylor marls			(5) Black soil
	0	3	(4) Basal pebble zone. Limestone pebbles and some fossils
Pecan Gap	5		(3) Hard white chalk with characteristic conglomerate zone of phosphate pebbles, phosphatized fossils, and glauconite at base
Wolfe City	4		(2) Chalky sands with sandy chalk lenses
	3		(1) Argillaceous yellow sands with abundant *Exogyra ponderosa*

Eastward from the foregoing section the Pecan Gap continues to thin until it is represented by only the basal conglomerate zone in western Red River County, and several miles east of Fulbright (Red River County) even this zone disappears from the section and upper Taylor marl rests on the Wolfe City or the Annona formation.

BASE OF UPPER TAYLOR MARLS

As the base of the upper Taylor marls exhibits some exceptional characteristics in eastern Lamar and western Red River counties, where the Pecan Gap disappears from the section, a brief description of this basal zone is given.

Outcrops of the basal upper Taylor marls have just been mentioned at Locations 5 and 6. One-half mile west of Milton (Sam Harvey tract, Joseph Deck Survey) at a roadside exposure the base of the upper Taylor marls is soft gray marl extremely rich in *Inoceramus* prisms and glauconite as disseminated grains which give the marl a salt-and-pepper appearance. At the base of this 5-foot exposure some brown, resinous, irregularly shaped pebbles (phosphate?) were found. This glauconitic zone extends eastward to the vicinity of Fulbright.

In the vicinity of Deport (Lamar-Red River County line) the glauconitic basal upper Taylor marls are represented by hard, reddish brown slab limestone. This slab limestone was nowhere found in place and the beds above and below it were nowhere seen in good continuous exposure. This limestone occurs in large flat slabs, 1–4 inches thick and varying from several inches to 4 feet in linear dimensions, lying in black-land fields or on weathered slopes. The slabs are very rich in *Inoceramus* prisms and might well be described as an "*Inoceramus* prism coquina." Glauconite is abundant as disseminated grains and the rock is firmly cemented with calcite. These slabs are well shown on the Deport-Fulbright road ½ mile north of Deport.

The transition from the soft upper Taylor marls to the hard limestone slabs appears in an exposure northeast of Deport.

Location 7, Fig. 1. Main secondary road north from Deport 0.9 mile; east on field road 0.7 mile; north 0.2 mile to creek. Exposure in creek on west side of road.

Here soft glauconitic marls rich in *Inoceramus* prisms show partial cementa-

tion to hard slabs. It is believed that the slab zones have their origin in secondary cementation and this exposure is a locality where cementation has not gone as far as it has in other areas.

East of Fulbright throughout Red River County all exposures of the upper Taylor marls show gray to white soft marls. The pebble zone and glauconitic phase were not found in the central and eastern part of this county. Eastward the upper Taylor marls rest on the Annona chalk but no good exposures of the contact were found.

SUMMARY AND CONCLUSIONS

The stratigraphic relationships of the formations discussed are shown in Figure 2 and the eastward thinning along the strike is readily apparent from a

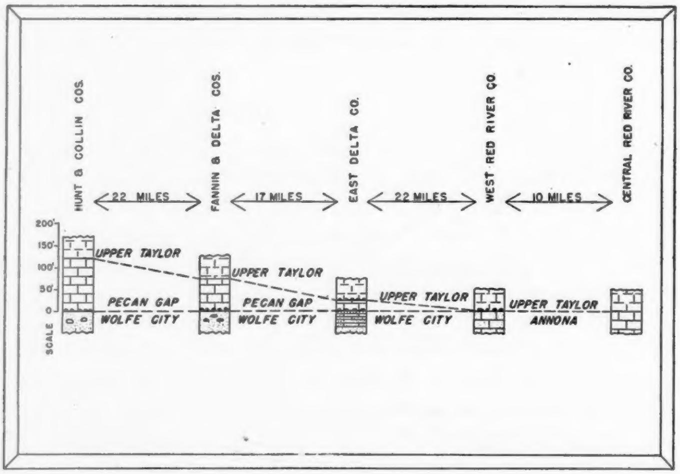


FIG. 2.—Measured sections showing eastward thinning of Pecan Gap formation.

study of these sections in Figure 2. In the western part of the area (Hunt and Collin counties) the contact between the upper Taylor and the underlying Pecan Gap chalk is transitional with no evidence of a break of any kind and here the Pecan Gap is approximately 120 feet thick. The base of the chalk is marked by a glauconitic conglomerate of phosphate pebbles and phosphatized fossils as previously described in the general description of this formation. Immediately underlying the Pecan Gap is the Wolfe City sand containing a great abundance of *Exogyra ponderosa* but *E. ponderosa* was not found in the Pecan Gap chalk.

Eastward in Delta County, the base of the upper Taylor is marked by a thin limestone pebble conglomerate immediately overlying the Pecan Gap chalk; the Pecan Gap is only 25 feet thick. The base of the Pecan Gap continues to be

marked by a phosphate pebble conglomerate rich in glauconite. The underlying Wolfe City sands contain a few chalky lenses and an abundance of *Exogyra ponderosa*, but *E. ponderosa* was not found in the overlying Pecan Gap.

The presence of a pebble conglomerate at the base of the upper Taylor marls together with the thin Pecan Gap section leads to the conclusion that a hiatus exists in this area and east of it between the upper Taylor marls and the Pecan Gap chalk and that the thin chalk section is due to erosion or non-deposition of the upper part of the Pecan Gap chalk section seen in Collin and Hunt counties. The pronounced eastward thinning of the Pecan Gap chalk is shown in Table I.

TABLE I

THICKNESS OF PECAN GAP CHALK, IN FEET

Southeast of Wolfe City (Hunt County)	70
South of Ladonia (Fannin County)	75
Pecan Gap (Delta County)	35
Enloe (2½ miles north, Delta County)	25
Bairdstown (4 miles southeast, Lamar County)	15
Milton (1 mile north, Lamar County)	5
Deport (Lamar-Red River County line)	3
Fulbright (Red River County)	1

Farther east in eastern Lamar County the Pecan Gap is only 5 feet thick, its upper limit being clearly defined by the limestone pebble zone at the base of the upper Taylor marls and the base by the typical basal Pecan Gap phosphate pebble conglomerate containing an abundance of glauconite. In this area the upper Wolfe City, immediately underlying the Pecan Gap, consists of chalky sands with numerous sandy chalk lenses, and contains abundant *Exogyra ponderosa*.

On the east side of a county road, ½ mile north of Deport near the Lamar-Red River County line, the Pecan Gap is only 2–3 feet thick; it is the basal conglomerate zone of phosphate pebbles, phosphatized fossils, and a little chalk. Below this pebble zone the surface is covered with *Exogyra ponderosa* and the soil is sandy; above it are the limestone slabs, previously described, which mark the base of the upper Taylor marls. East of Fulbright (Red River County) the Pecan Gap has disappeared from the section and the upper Taylor marls rest on the Wolfe City or Annona chalk. In the discussion of the Wolfe City formation earlier in this paper it has been pointed out that the Wolfe City becomes more and more chalky toward the east until it is finally represented by a slightly arenaceous chalk, lithologically indistinguishable from the Annona chalk near Clarksville.

It has been shown that:

1. *Exogyra ponderosa* was not found in the Pecan Gap chalk but was found in abundance in the upper Wolfe City and Annona chalk.

2. The Pecan Gap formation thins from 120 feet in Hunt County to zero feet in Red River County.

3. The Wolfe City formation can be traced north and east from Collin County to Red River County and it becomes more and more chalky toward the east until it is a slightly arenaceous chalk.

The stratigraphic relationships and facies changes of the formations discussed in this paper are diagrammatically shown in Figure 3. The writer believes that the foregoing field evidence leads to only one conclusion: the Wolfe City formation is the age equivalent of the Annona formation as developed in northeastern Texas.

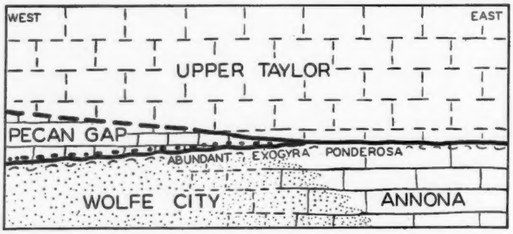


FIG. 3.—Diagrammatic section showing relationships between upper Taylor, Pecan Gap, Wolfe City, and Annona formations.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 4 (APRIL, 1944), PP. 531-540, 2 FIGS, 2 PLATES

"CORNIFEROUS" AT IRVINE, ESTILL COUNTY, KENTUCKY

A. C. McFARLAN, L. B. FREEMAN, AND V. E. NELSON
Lexington, Kentucky

ABSTRACT

The "Corniferous" as a name for an important producing zone in Kentucky has been something of a catch-all for a number of different Silurian and Devonian limestones underlying the Ohio shale, a matter of unconformity and regional overlap. A thick Silurian limestone section east of the Cincinnati arch wedges out westward in the vicinity of Irvine. This stratigraphic trap has been productive in the Irvine-Big Sinking field, and in the Ragland and Menifee pools.

Erosion remnants of this Silurian wedge are recognized in outcrop in the vicinity of Irvine, Estill County, overlapped by the eastward feathering edge of the Boyle limestone. These stratigraphic relationships in outcrop give an insight into the complicated underground situation in the near-by productive area. Subsurface studies in the vicinity complete the picture.

The "Corniferous" has been a major producer of petroleum in Kentucky, but the term has been something of a catch-all for any producing zone a short distance below the Black shale. The particular limestone, or limestones, vary from place to place so that a number of different formations are involved. This is mainly a matter of unconformity with regional overlap by middle Devonian limestones and the Ohio shale truncating successively older formations toward the axis of the Cincinnati arch.

At the outcrop in Kentucky, the overlap is by the Jeffersonville limestone in the west, and the Boyle limestone in the southwest and east. In some places the black shale cuts through to the underlying rocks. Subsurface work has shown that while there is an extensive Jeffersonville (Grand Tower) overlap from the west, it was succeeded by a Hamilton (Sellersburg-Boyle) overlap on a grander scale. This invasion apparently was from the west and southwest, and extended east to the region around Irvine, Kentucky. From Irvine to eastern Morgan County, the mid-Devonian has not been found in well samples (Freeman, 1941). In this region it is the Ohio shale that truncates the eastward-dipping Silurian succession.

This paper involves a further study of the "Corniferous" in the vicinity of Irvine. Field work on the outcrop was carried on by McFarlan and Nelson. Subsurface correlations were made by Freeman.

The Ribolt, Bisher, and Lilley are recognized in outcrop as erosion remnants beneath the Black shale. Locally the "Corniferous" is represented by the Bisher and Lilley in the form of a buried hill against the flanks of which the Boyle limestone abuts. These observations extend the known occurrences of these formations in outcrop far south of the Ohio River. They add to the picture of the stratigraphic complexity of the producing zones. Proximity to producing pools makes these occurrences significant.

Several outcrops of exceptional "Corniferous" are of particular interest. These are figured on Plates 1 and 2, and are discussed in the explanation of these plates. They occur in a region in which the normal section intervening between the Estill clay (Crab Orchard) and the Ohio shale is 20–25 feet of Boyle limestone, the upper cherty part of which has gone under the name of Casey.

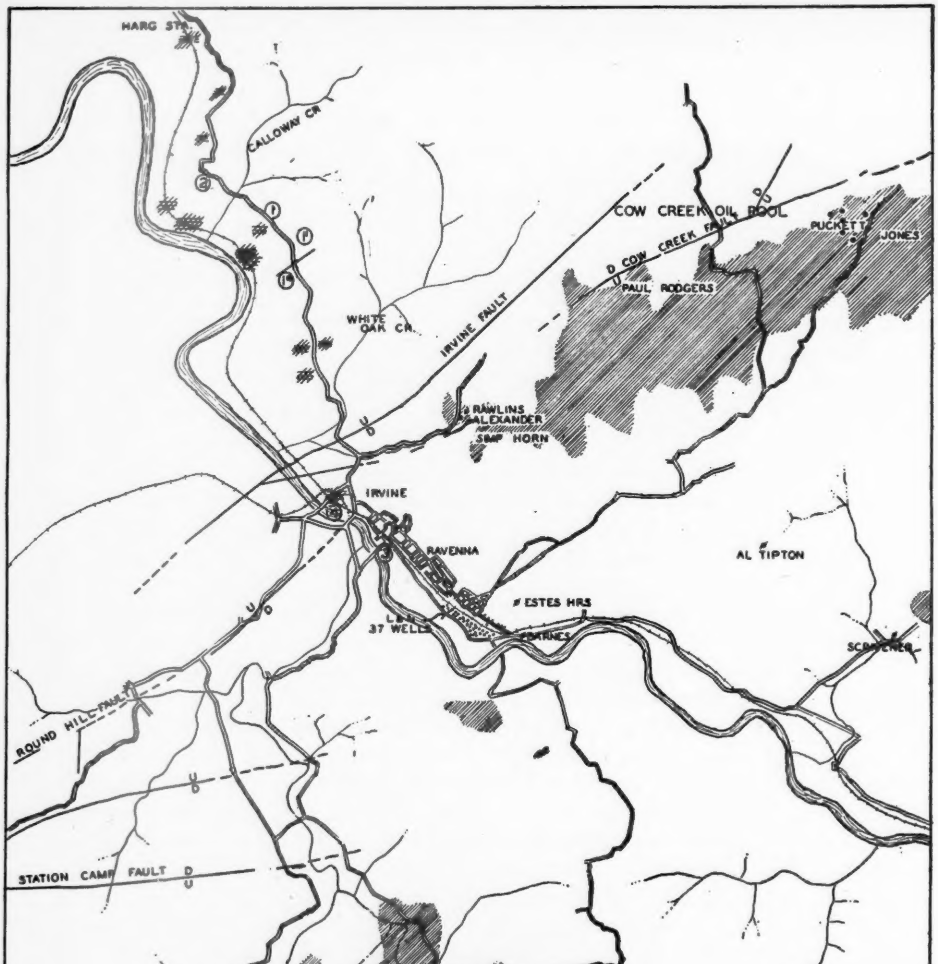


FIG. 1.—Outline map of Irvine, Estill County, and vicinity. Localities referred to in explanation of Plates 1 and 2 are indicated by number (1, 2, *et cetera*)—Bisher and Lilley outcrop. Cross-hatched areas are Boyle outcrop.

Round Hill fault (direction of displacement and continuity of fault incorrectly shown on Kentucky Geological Survey Estill County map) may be traced northward to the broad flood plain of the Kentucky River. While directed toward the southeast end of the section shown in Plate 2, the fault can not be recognized north of the river and apparently has died out.

SILURIAN AND DEVONIAN STRATIGRAPHY OF CENTRAL KENTUCKY

SILURIAN

East of Cincinnati Arch

Cayugan	Greenfield	
Lockport	Peebles[1] — — — Lilley[1] — —	
Clinton	Bisher[2] Ribolt Estill Waco Lulbegrud Oldham	Crab Orchard
Medinan	(Plum Creek) Brassfield	

[1] The important Corniferous "pays" of the Irvine pool.
[2] The lower "pay" of the Big Sinking pool, also the Big Six "pay" of eastern Kentucky.

DEVONIAN

Genesee Tully	West of Cincinnati Arch New Albany (including Duffin)		East and South of Cincinnati Arch Ohio—Chattanooga (including Duffin)
Hamilton	Sellersburg	Casey Beechwood Silver Creek	Boyle {Casey —
Onondaga		Jeffersonville	—

The various exposures shown in Plates 1 and 2, significant in connection with oil and gas production on the east, also help answer the question as to whether the absence of much, and in many places all, of the Silurian in the vicinity of the axis of the Cincinnati arch was due to non-deposition, or pre-Onondaga-Hamilton erosion. The exposures of the Bisher, Lilley, and probably Peebles, are along the feathering and deeply eroded western edge of these beds as they are met and overlapped from the west by the feathering edge of the Boyle limestone. The belt of overlapping Boyle and Bisher-Niagaran is narrow.

SUBSURFACE

Cuttings have been examined from thirty-seven wells drilled by Wittmer and Dyer in the pool on the Louisville and Nashville Railroad properties at Ravenna, Estill County. Several sets of cuttings have been examined from wells offsetting this property, from wells northeast of the pool near the mouth of Cow Creek, and from scattered wells elsewhere in the county. Except in the case of the

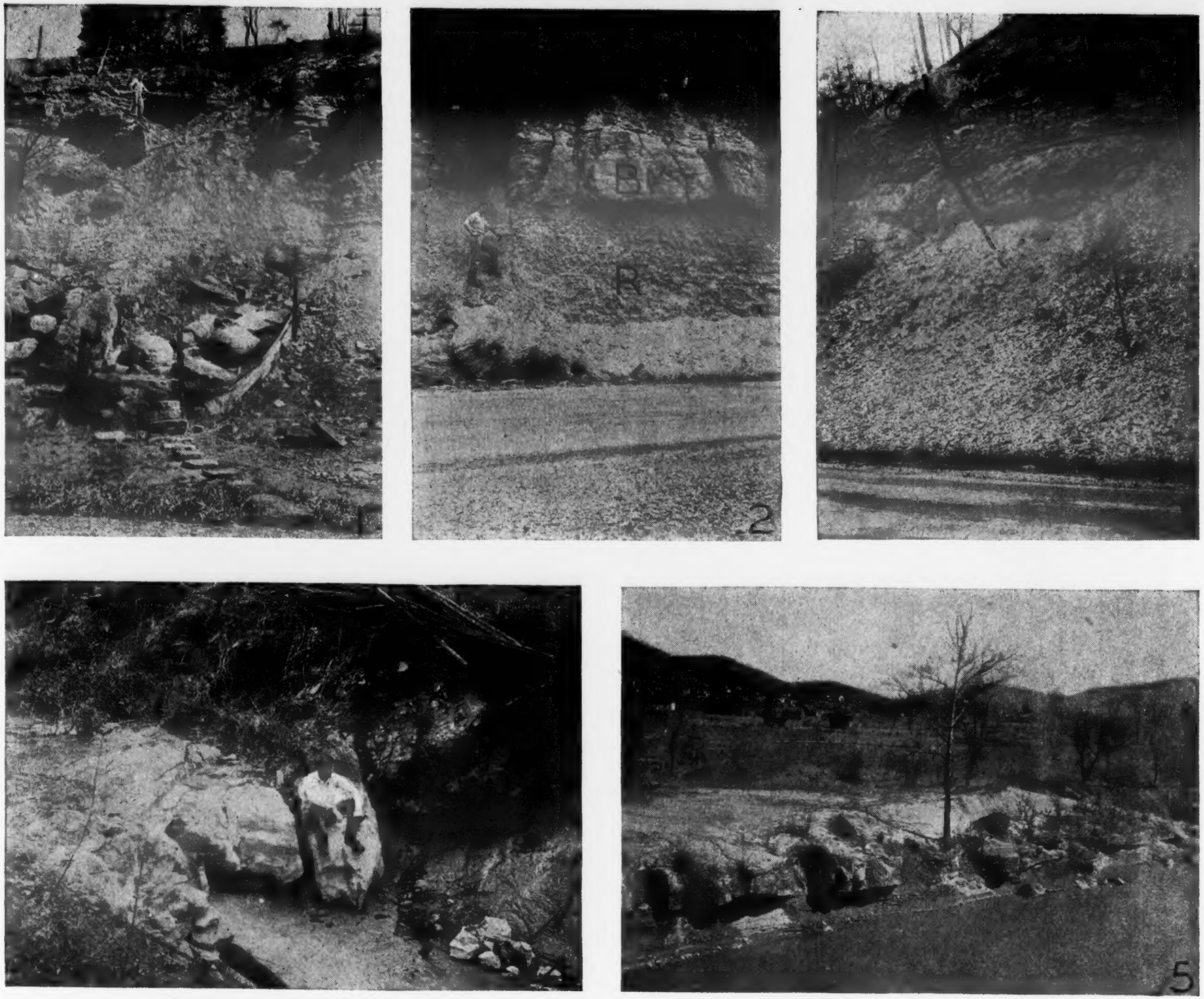


PLATE 1

PLATE I

FIG. 1 (Loc. 1).—Road cut 3½ miles north of Irvine and 2½ miles south of Harg Station on Ky. 89 where material has been removed to make the highway fill across the bottoms of Calloway Creek. A measured section shows:

		Feet	*Inches*	
	(g)			Ohio shale
	(f)	8		Covered
Bisher	(e)	11		Interbedded gray shale and thin dolomitic limestone
Bisher	(d)	1		Dolomitic limestone in two beds, upper one coarsely crinoidal
Bisher	(c)	2	4	Similar to (a)
Bisher	(b)		8	Shale
Bisher	(a)	4	4	Porous somewhat crinoidal massive dolomitic limestone
Ribolt				Gray shale with considerable interbedded thin dolomite

There is a total of 19 feet of exposed Bisher and a covered zone of 8 feet between it and the Ohio shale above. Across the road southwest, and 200 yards away, the typical Boyle limestone occupies the same interval in the section.

FIGS. 2 and 3 (Loc. 1′).—Road cuts on opposite sides of the highway, ½ mile south of 1. In the cut shown in Figure 3, a 24-foot section of dolomitic limestone is exposed and cut by a small fault. The upper 6 feet is coarse-grained, highly crinoidal, and identified as Lilley on the basis of exposures to the south (Fig. 4). It is deeply weathered, very porous and much of it crumbly. The rest is Bisher. Loose blocks at the base of the cut have yielded an abundance of the characteristic Bisher *Whitfieldella cylindrica*. In Figure 2, Bisher containing *Whitfieldella* rests on Ribolt.

FIG. 4 (Loc. 1″).—Creek exposure along side of the road and 100 yards south of 1′. The Lilley is faulted down against, and on, the Crab Orchard with downthrow to the southeast and vertical displacement of about 15 feet. The Lilley here is hard crinoidal limestone showing little porosity, but intermediate stages of weathering between it and the deeply weathered porous rock previously mentioned are shown in the creek bank. The blue-gray fresh rock turns brown and red on weathering. Characteristic *Cladoporas* are fairly common.

Loc. 2.—A half-mile north of (1) and just west of the road, an isolated boulder of Lilley shows black shale wrapped around its upper surface.

In none of these exposures does the Boyle limestone overlap the Lilley. Instead, the Bisher-Lilley succession occupies the same Crab Orchard-Ohio shale interval normally occupied by the Boyle, and constitutes a pre-Boyle buried hill. The Bisher-Lilley rocks, occupying the same interval as the Boyle, at first sight appear to be a lithologic facies of it, and the exposure shown in Figure 5 was referred to as such by the senior writer in 1943.

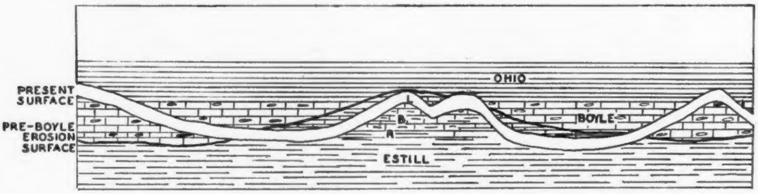
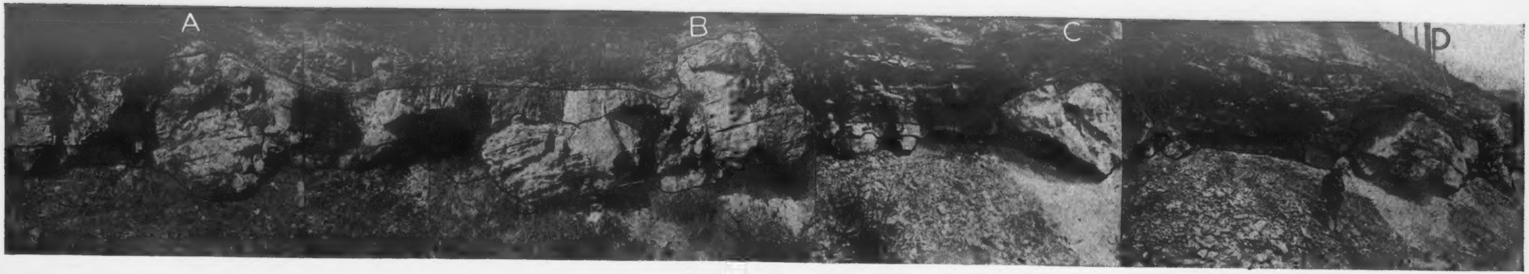
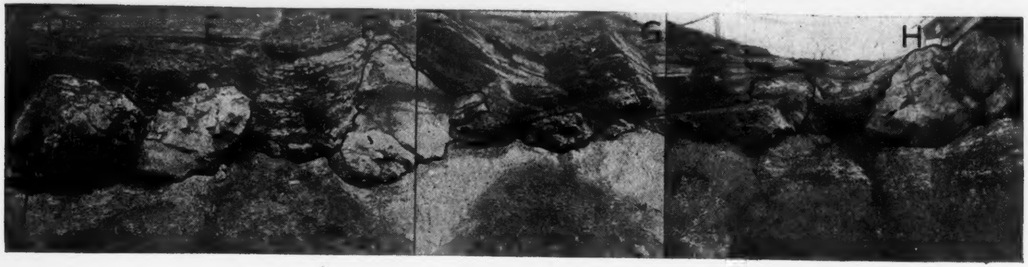


Diagram of relationship of Boyle limestone to Bisher and Lilley formations at Loc. 1, 3½ miles north of Irvine. Boyle abuts against flanks of a hill formed of Bisher and Lilley.

FIG. 5 (Loc. 3).—Outcrop in the northeast bank of the Kentucky River beneath the old bridge at Irvine. The rock, a deeply weathered, soft, porous dolomitic limestone, is Bisher, dipping downstream under cover. Within less than a mile southeast the "Corniferous" is productive in the Ravenna pool. Proximity to outcrop suggests that the Ravenna "pay" is Bisher. Freeman finds that both Boyle and Bisher produce.





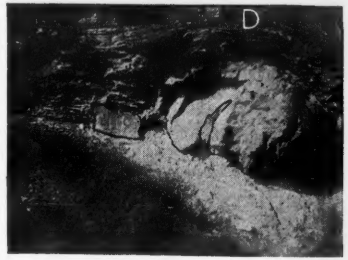


PLATE 2

Ravenna pool and a few wells outside the pool areas of Estill County, samples of the cuttings had not been saved. Thus, the subsurface geologic picture is incomplete.

In every case within the Ravenna pool the Devonian cherty limestone (Boyle) is present and is separated from the base of the black shale only by some pyrite and a few grains of coarse, rounded and frosted quartz sand. The Boyle can be zoned due to the differences in the character of the cherts. It varies in thickness from 2 to 15 feet. In some wells, the black shale rests on the upper cherty dolomite which is recognized by light to dark gray, dense chert which typically is spiculose. In places the shale rests on the more or less crinoidal dolomite which intervenes between the upper heavy chert ledge and the lower cherty part where the chert is lighter gray in color, semi-translucent, spiculose, and contains dark carbonaceous inclusions. In some wells only the lower chert is present, and where this is true the lower part of the section has been subjected to weathering and the chert shows leaching. This leached zone makes a good horizon marker within a limited area.

The Boyle rests on varying thicknesses of Silurian dolomite. None of the wells

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PLATE 2

Section exposed in Louisville and Nashville Railroad cut at the new bridge over the Kentucky River at Irvine (Loc. 4).

The stratigraphic section includes:

(d) Ohio shale with interbedded dolomite in lower part which has commonly been regarded as Duffin
(c) Casey limestone, the cherty upper Boyle. Here only 6 feet thick, it constitutes entire Boyle section
(b) Large boulders of massive gray dolomite, some of it crinoidal
(a) Crab Orchard (probably Ribolt) shale

Significant observations include:

1. The Ohio shale sags in between the blocks of limestone, a matter of compacting and sagging following deposition, not later disturbance.

2. Typical cherty Casey limestone crops out 350 feet up the track from "A." It may be traced with only a minor break to "A" where it is 5 feet thick and only the upper 1 foot contains chert. Toward the southeast it feathers out in the troughs "AB" and "BC" between boulders and overlaps the tilted edges of the lower parts of the latter (see "B").

The Casey turns up sharply on both sides of boulder "A" and wraps itself around the top of it. It also turns up sharply on both sides of "B" and against "C." It is a deposit laid down in these troughs and unconformably overlies and overlaps the crinoidal rock (see "A"–"B").

3. The simulated anticline "BC" and syncline "CD" are tilted and isolated blocks, the false impression of continuity between "B" and "C" being given by the 1 foot of Casey limestone in that trough.

4. Stratigraphic identification of the boulders offered some difficulty. As indicated above, they are pre-Boyle. The lithology varies, but some of the boulders are the counterpart of the Lilley shown in Plate 1, Fig. 4. Others may be Peebles, but all are one or the other of these Niagaran dolomites which are well known sources of oil a few miles northeast under cover.

5. Solution played a prominent rôle in removing the Niagaran. Deep solution channels in the base of the blocks are shown at "B" and "D." Squeezing up of the Crab Orchard shale into these and other re-entrants in the base of limestone may have been in part from pressure of the weight of overlying strata, but mainly from pressure associated with faulting in the vicinity. (See outline map, Fig. 1.) That the land was low at the time of erosion is indicated by these solution channels. The rock could not have been much above the water table, for any active stream would have knifed rapidly into the weak underlying shale.

was drilled completely through the section into the green shales below, and many of them were not drilled through the Boyle. However, vertical lithologic changes within the Bisher section make it possible to zone it and the correlation of these zones indicates that the Boyle does not everywhere rest on the same zone.

The thickest Bisher section shows, at the top, gray dolomite, evenly crystalline with the texture of a sandstone, with no chert or only rare fragments of chalcedony. Beneath this is gray-brown dolomite with inclusions of darker, slightly argillaceous fragments, in places with thin breaks of very fissile gray

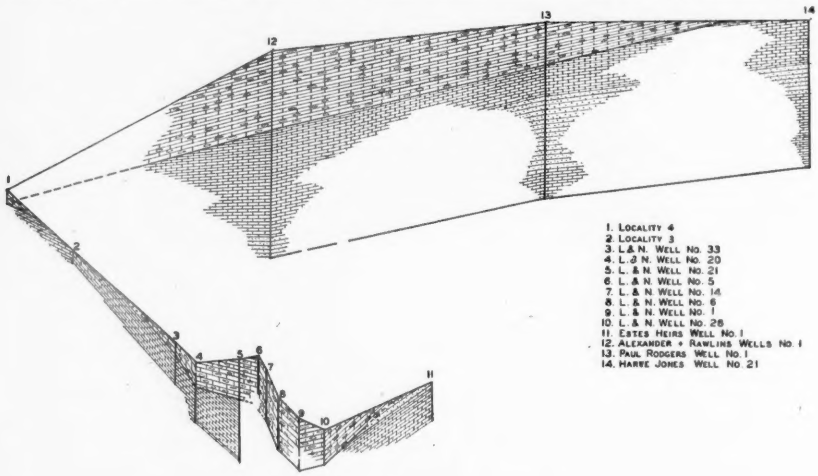

Fig. 2

shale. Underlying this the dolomite looks like a fossiliferous and crinoidal gray limestone, and in some places the dolomite seems almost to have assumed the crystal habit of calcite. In some wells this dolomite is broken up very finely and is more cream-colored where it contains water. In a few wells the Devonian chert rests on this layer.

The thickest section of Devonian measured above the weathered chert crosses the area of best production, which in this pool has a northeast-southwest trend, at about a 60° angle. The thickest section of Silurian is in the area of best production and the best well on the lease is in that part of the lease where the thick Silurian crosses the thick Devonian section. However, this well was not drilled through the Devonian chert and is thus producing entirely from it.

The Ravenna wells are located 1–1½ miles south and southeast from the outcrop (Loc. 3, Plate 1, Fig. 5). Production in this pool comes from both Boyle and Bisher, and is characterized, as in near-by pools, by a distinct water drive. The permeability is such that great care must be exercised to maintain the proper oil-water pressure ratio or the water by-passes the oil and ruins the well.

A similar stratigraphic section is found in an extension of the trend of production northeast from the Louisville and Nashville Railroad wells into the Irvine pool. In wells at the southwest end of this pool and as far east as the Paul Rodgers No. 1, drilled by the Wood Oil Company, the Boyle cherty dolomite overlies the Bisher, and perhaps Lilley, producing zones. However, in the area about 2 miles east of the Rodgers well the Petroleum Exploration has been repressuring wells, and cores from these show no sign of Devonian between the black shale and the Silurian porous dolomite and sandy dolomite (Bisher). A composite section made from samples obtained from two wells drilled on the Alexander and Rawlins farms just north and east of Irvine indicate that there is about 25 feet of Devonian cherty dolomite present and about 50 feet of Bisher.

No samples are available from the wells of the Station Camp pool southwest of the Ravenna pool, but samples from the Collins Heirs' well No. 1 on the Middle Fork southwest of Station Camp have no Devonian at all and the black shale rests on Silurian which lithologically is different from the normal section and is very similar to western Kentucky Niagaran with pink crinoidal limestone interbedded with the dolomite. Wells drilled south of Ravenna near the Jackson County line, southeast of Station Camp, have no Devonian limestone.

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FREEMAN, L. B., "Devonian Subsurface Strata in Western Kentucky," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (1941), pp. 668–712.

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———, "Big Sinking Field, Lee County, Kentucky," *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol. (1941), pp. 166–207.

The Bisher is added to the list of producing zones and the buried anticline is indicated to have been important particularly in that secondary porosity developed in strata exposed on its flanks. The mid-Devonian is not present in this field, nor is it known west of eastern Morgan County.

JONES, D. J., and MCFARLAN, A. C., "Geology of the Big Sinking Pool, Lee County, Kentucky," *Univ. Kentucky Bur. Min. and Topog. Survey*, Ser. 7, Bull. 1 (1933). 9 pp., 9 pls.

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LAFFERTY, R. B., "Central Basin of Appalachian Geosyncline," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 5 (1941), pp. 781–825.

The upper "Corniferous" gas pay of Boyd, Johnson, and Magoffin counties is regarded as Helderberg and about the equivalent of the Austinburg ("First Water of the Big Lime" of Ohio).

———, and THOMAS, R., "'Corniferous' in Eastern Kentucky and Western West Virginia," read before the American Association of Petroleum Geologists at Denver, April 24, 1942.

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MCFARLAN, A. C., "Unexposed Silurian Section and Producing Zones of Irvine Oil Field, Estill County, Kentucky," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 10 (1938), pp. 1447–56.

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———, "Cincinnati Arch and Features of Its Development," *ibid.*, Vol. 23, No. 12 (1939), pp. 1847–52.

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Production comes from the beveled edges of Silurian limestones capped by the black shale. Two pays known as the "Corniferous" and "Blue sand" are regarded as in the Louisville and Laurel.
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WILSON, C. W., "The Pre-Chattanooga Development of the Nashville Dome," *Jour. Geol.*, Vol. 43, No. 5 (1935), pp. 449–81; 1 pl., 8 figs.; (abstract), *Tennessee Acad. Sci. Jour.*, Vol. 10, No. 2 (1935), pp. 104–05.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 4 (APRIL, 1944), PP. 541-553, 10 FIGS.

GRABENS IN GULF COAST ANTICLINES AND THEIR RELATION TO OTHER FAULTED TROUGHS[1]

WILLIS G. MEYER[2]
Dallas, Texas

ABSTRACT

Grabens are present in many of the domes and anticlines in the Gulf Coast of Louisiana and Texas. In some cases, these grabens are believed to overlie horsts to form graben-and-horst structures. This type of structure probably exists in many uplifted areas outside the Gulf Coast province. In areas where grabens or horsts are exposed at the surface or are encountered at shallow depths, the possibility exists that they may be segments of graben-and-horst structures. Geophysical and surface geological data on rift valleys show certain similarities with graben-and-horst structures in Gulf Coast anticlines. These similarities suggest that rift valleys may be the exposed upper part of large graben-and-horst structures formed as a result of the crustal uplift present in areas traversed by rift valleys.

INTRODUCTION

Grabens are found in many domes and anticlines in the Gulf Coast of Louisiana and Texas. In some places they overlie salt plugs, in others they are in domes generally believed to be underlain by deep salt, and in a third group they are in anticlinal structures that are probably not associated with salt. Grabens varying in size from those observed on the Gulf Coast to some of great magnitude also have been reported in other areas of pronounced uplift. This presence of downfaulted blocks directly over intruded or sharply upfolded rock masses arouses speculation on the nature of the basal structure of grabens and the manner in which space compensation for the downfaulting of a rock mass over an uplift is effected. A wealth of subsurface data is generally available on oil-field structures, particularly those on the Gulf Coast. It is, therefore, possible to study them in considerable depth, an advantage not enjoyed to any great extent in other areas where grabens are found.

The purpose of this paper is to consider three possible systems of faulting which may be present wherever grabens are found. Two of these are well known, and one or the other has generally been assumed to represent the type of structure into which grabens develop in depth. The third system has heretofore received little or no consideration. It is, however, consistent with certain data from Gulf Coast structures and from some areas outside the Gulf Coast, and it may represent the structure of many grabens of all sizes in the earth's crust.

GULF COAST GRABENS

Some of the oil fields in which grabens are found are: the Conroe field, Mont-

[1] Manuscript received, December 4, 1943.

[2] Consulting geologist, DeGolyer and MacNaughton, Continental Building. All illustrations, except Figures 5, 6, and 7, are by E. E. Hurt, and the electrical logs in Figure 4 are published through the courtesy of the operating companies.

gomery County,[3] the Raccoon Bend field, Austin and Waller counties,[4] the Tomball field, Harris and Montgomery counties, the Orange field, Orange County, all in Texas,[5] and the Cheneyville field, Rapides Parish, Louisiana. Salt has been encountered only in the Cheneyville field.

Viewed in the abstract, three fault systems which would allow the formation of a graben over an upward moving mass of rock are possible. First, both faults may terminate in depth at or above the line of convergence of the faults. Second, one fault may extend beyond the line of convergence while the second fault terminates against the first. Third, the faults may cross and form a horst beneath the graben,

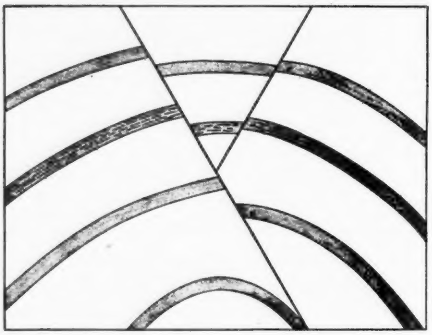

FIG. 1.—Cross section of graben in anticline in which one fault ends against the other.

a pattern herein referred to as a "graben-and-horst" structure. Probably all three types of structures exist.

In the first case, where neither of the faults extends beyond the line of convergence, space compensation is entirely by rock flow. A structure of this kind is described by G. C. Gester and John Galloway[6] and by Stuart K. Clark.[7] These are multiple fault systems, but the larger pattern, according to the interpretation of the authors, is of this type. Although this type of structure must be considered a possibility wherever a graben is present, it is not applicable if faulting is observed below the line of convergence of the master faults. Furthermore, since downdropping of the rock between the faults is by rock flow only, the throw of opposing faults should be nearly equal. Therefore, this type of structure is prob-

[3] Frank W. Michaux, Jr., and E. O. Buck, "Conroe Oil Field, Montgomery County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 6 (June, 1936), p. 746.

[4] L. P. Teas and Charis R. Miller, "Raccoon Bend Oil Field, Austin County, Texas," *ibid.*, Vol. 17, No. 12 (December, 1933), p. 1471.

[5] Alexander Deussen and E. W. K. Andrau, "Orange, Texas, Oil Field," *ibid.*, Vol. 20, No. 5 (May, 1936), pp. 543–48.

[6] G. C. Gester and John Galloway, "Geology of Kettleman Hills Oil Field, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 10 (October, 1933), p. 1188.

[7] Stuart K. Clark, "Classification of Faults," *ibid.*, Vol. 27, No. 9 (September, 1943), pp. 1258–60.

ably not present wherever opposing faults have greatly dissimilar amounts of throw.

In the second case (Fig. 1), a substantial amount of rock flow is required because void space would be formed by this system of faults if the rock mass were completely rigid and did not flow. Credence is attached to this possibility by the laboratory models of Cloos[8] and others which show approximately this sort of structure by submitting wet clay to tension by means of a movable support. Largely on the basis of these models, this type of structure has often been assumed for the Rhinegraben and for many other fault troughs. This type of fault

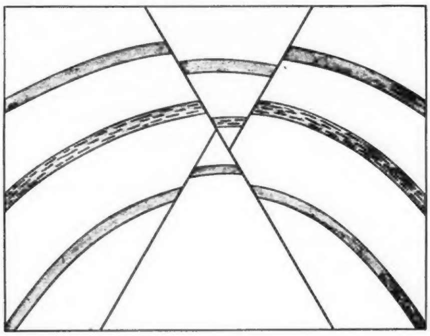

FIG. 2.—Cross section of anticline in which graben faults cross and form a horst below.

system probably exists in some Gulf Coast oil-field structures. Such a system is easy to visualize, for example, in South Cotton Lake field, Chambers County, Texas,[9] where a fault with a throw of less than 50 feet opposes one with a throw of nearly 400 feet.

The third fault system, which is believed to be present in a number of areas, is shown in cross section in Figure 2. In this case, the faults cross and form a horst beneath the graben, the plug itself being a part of the horst in the case of salt domes.[10] By this system of faults, the downdropping of a fault block against an upward intruded or sharply upfolded rock mass is possible, and the necessary lateral extension of the strata over the top of the anticline is achieved. This graben-and-horst structure may be defined on either side by several faults instead of one. The structure may be further complicated by associated faults oblique to, or at right angles to, the master faults.

[8] Walter H. Bucher, *Deformation of the Earth's Crust* (1933), pp. 337–38.

[9] Joseph M. Wilson, "South Cotton Lake Field, Chambers County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 10 (October, 1941), pp. 1916–17.

[10] A type of structure similar to this is illustrated in a paper by J. M. Bugbee, "Reservoir Analysis and Geological Structure," *Petrol. Tech.*, Vol. 5, No. 6 (November, 1942), pp. 1–12. Figure 2, "Diagrammatic Strain and Fault Patterns of Incompetent, Gravitational-Type, Deep-Seated Structures," is used to illustrate the effect on water drive of "reservoir discontinuities effected by faulting."

Figure 3 shows in cross section the results where the graben and horst are defined by two faults on one side and three on the other. It can be seen how complicated such a structure appears when mapped on any datum in the zone of intersection of the faults. Yet the basic pattern of this structure is identical with that of Figure 2 and with such relatively simple structures as Tomball and Conroe fields appear to be when mapped on the top of the Cockfield.

Graben-and-horst faulting as a minor structural feature has been recognized by a number of geologists. One such feature in Eola field, Avoyelles Parish, Louisiana, has been described by Bates.[11] There is not sufficient information available in Eola field, however, to determine the nature of the deep fault pattern.

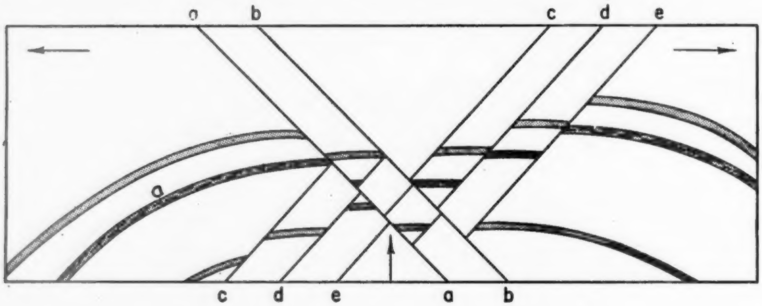

FIG. 3.—Graben-and-horst structure defined by two faults on one side and three on the other.

Available subsurface data from Cheneyville field, Rapides Parish, Louisiana, fit well into a graben-and-horst interpretation. The strata over the salt are cut by two master faults which strike approximately east-west. Salt or cap rock has been encountered in two wells in this field. These are the Amerada Petroleum Corporation's Weil Company, Inc., No. 4 and No. 5. A south-north cross section through these and adjacent wells is shown in Figure 4. Allowing for a small range of error, a detailed examination of this section shows that faulting has cut out 250 feet of section at a depth of 5,450 feet and 650 feet at a depth of 5,700 feet in the No. 5 well. A highly brecciated zone was encountered in this well at a depth of 6,695 feet. The loss of section there is large but can not be accurately determined. Faulting has cut out 650 feet of section at a depth of 5,825 feet and 650 feet at a depth of 6,130 feet in the No. 4 well. Cap rock was encountered in the former at 6,812 feet and at 6,680 feet in the latter. Approximately 125 feet of section are cut out at a depth of 4,900 feet in The Texas Company's Weil Company, Inc., No. 2, and 200 feet at a depth of 4,900 feet in the Amerada Petroleum Corporation's Weil Company, Inc., No. 8. For reasons given later, the uppermost of the two north-dipping faults probably ends against the opposing master fault instead of crossing it and is of small magnitude in comparison with the master faults.

[11] Fred W. Bates, "Geology of Eola Oil Field, Avoyelles Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 7 (July, 1941), Fig. 5, p. 1372.

These data on position and throw of faults fit into the graben-and-horst type of structure as illustrated in Figure 4. This interpretation is strengthened by the fact that the Amerada Petroleum Corporation's Weil Company, Inc., No. 4 is the lowest well on beds between the depths of 5,500 feet and 5,800 feet but is the high-

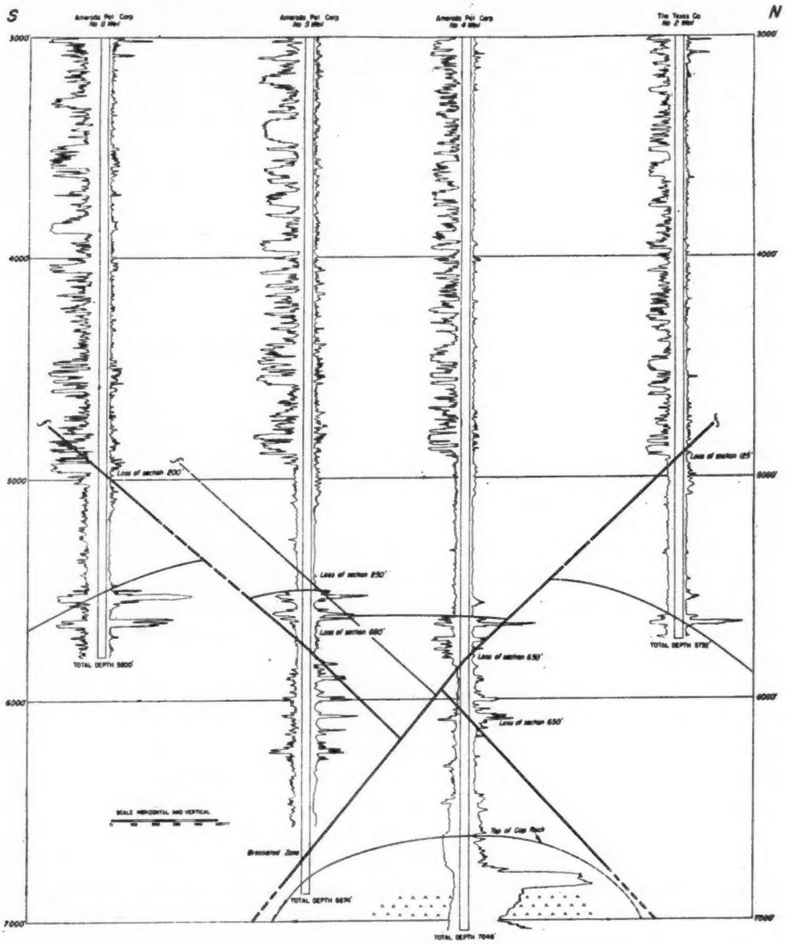

FIG. 4.—Graben-and-horst interpretation of data at Cheneyville field, Rapides Parish, Louisiana.

est well on the salt and on the beds immediately above the salt. It is difficult to escape the implication that this well is in a graben at 5,500 feet and in a horst at 6,500 feet, it being noted that two large faults are encountered between these depths. It can be contended, with justification, that an insufficient number of

wells have reached the salt to prove fully the type of structure present. However the available data fit better into the graben-and-horst type of structure than into alternative interpretations.

Numerous faults striking principally east-west and north-south are present over the entire field in shallow beds above the master graben-and-horst system. A distinctive feature of the Cheneyville structure is that these shallow faults have displacements of the order of magnitude of 50–250 feet in throw, while the faults in the zone approximately within 1,200 feet above the salt are more than 600 feet in throw. This transition occurs in a very short vertical distance, and there is considerable uncertainty in following the master faults into the shallower strata. For this reason, conclusions on the deep structure can not be based with certainty on the fault system in the shallow beds.

Two possible explanations exist for this sudden change in the throw of the faults in Cheneyville. First, it is apparent that deformation of sediments above salt plugs may arise either from the upward thrusting of salt plugs after the sediments are deposited or from differential compaction which would cause subsidence in the peripheral areas, resulting in tension and deformation of the sediments over the plug. After a salt plug becomes static, the column of rock containing the salt plug must compact less than adjacent columns composed mainly of shale and sand. Beds deposited over the plug would then be stretched as they occupied a lower position around the plug than over it. Over any salt dome buried by several thousand feet of sediment, we thus have the possibility of two separate systems of faults, one immediately above the salt plug resulting from the last upward movement of the plug and the other resulting from differential compaction. The former would involve sediments over the plug deposited previous to the last salt movement, while the latter could involve all sediments above the salt. It is probable that in the beds deposited before the last salt movement, some of the stresses resulting from differential compaction would be relieved by rejuvenation of old faults initiated by salt intrusion. This last movement along these old fault planes could extend upward into younger beds deposited after the last salt movement. This presents the possibility that faults of relatively large magnitude near the salt might be continuous with much smaller faults in overlying beds. If this did occur, the change in throw would take place abruptly and would be entirely different from the frequently observed phenomenon of progressive increase in throw with depth. It does not follow, of course, that all faults resulting directly from salt movement are continuous upward with those resulting from differential compaction.

The second possible explanation for a sudden increase in the throw of faults over salt plugs is based on the possibility of two or more relatively small movements of the salt plug after the deposition of the oldest beds above the salt. If each movement was separated from the next by a considerable interval of time when more sediment was deposited above the salt, it is obvious that faults in the lower beds nearest the salt would have the cumulative effect of all movements, while progressively higher beds would be affected by fewer salt movements. Cor-

respondingly, the throw of the faults in the higher beds would be less than of those in the lower beds. Such changes in the throw of faults resulting from several separate salt movements would take place abruptly at intervals and would not be distributed gradually over large vertical distances. To explain all faulting over a salt dome in this way necessarily requires salt intrusion after an overburden of many thousands of feet has accumulated, for faulting commonly involves great thicknesses of sediments over salt plugs.

In the case of Cheneyville, proof for either of the previous explanations is lacking at the present time. The first alternative, that of one movement of the salt combined with the effect of differential compaction, is favored by the uncertainty of tracing the large faults near the salt into the overlying beds and by the seemingly inevitable presence of stresses in the beds over the plug as a result of differential compaction. Furthermore, if it is true, as has been frequently postulated,[12] that the movement of the salt took place more or less concomitantly with deposition of the sediments and consequently with a relatively thin covering at any time over the top of the salt plug, some cause in addition to upthrusting of the salt is required because thousands of feet of sediment over the Cheneyville salt plug are involved in the faulting. This postulated history of salt domes is consistent with but not essential to differential compaction as a cause of faulting in the shallow beds. The chief requirement is a static condition of the plug after the deposition and faulting of approximately 1,200 feet of sediment over the top of the plug. If this is the case, then the faults in the zone within 1,200 feet above the salt are of greater displacement than those observed at higher levels because the former are due to the actual uplift of the salt mass, while the latter are due to differential compaction.

In either case, there are two different periods of faulting and probably two different causes of deformation. For this reason it is improbable that the uppermost of the two north-dipping faults in Figure 4 crosses the opposing master fault and continues downward. This is a relatively small fault and is probably related to the upper system. Furthermore, there is no evidence for this fault in the Weil Company, Inc., well No. 4 unless it crosses at the exact piercement point of the opposing master fault.

GRABENS IN ANTICLINES OUTSIDE GULF COAST

Grabens have been found in anticlines outside the Gulf Coast. An excellent example has been described by Claude C. Albritton, Jr.,[13] in the Malone Mountains of Texas. In an anticline known as Gyp Hill, two normal faults, each having

[12] Donald C. Barton, "Mechanics of Formation of Salt Domes with Special Reference to Gulf Coast Salt Domes of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 9 (September, 1933), pp. 1025–83.
L. L. Nettleton, "Fluid Mechanics of Salt Domes," *ibid.*, Vol. 18, No. 9 (September, 1934), pp. 1175–1204.
Paul Weaver, "Discussion," *ibid.*, Vol. 18, No. 9 (September, 1934), p. 1201.

[13] Claude C. Albritton, Jr., "Stratigraphy and Structure of the Malone Mountains, Texas," *Bull. Geol. Soc. America*, Vol. 49 (December, 1938), Pl. 1, Sec. A-B and p. 1802.

a throw of 500 feet and a heave of 150 feet, bound a graben. Subsurface data are lacking in this area, but if one extrapolates the dip calculated from the throw and heave given by Albritton, these faults would cross at a rather shallow depth.

Stephen Taber[14] has also described a number of anticlines cut by grabens in Utah. The deep phases of these structures are unknown but the idea of intersecting faults continuing in depth to form a graben-and-horst structure does not appear inconsistent with the known facts. That horsts are formed in anticlines in this area is indicated by the fact in the "Farnham[15] dome, a horst has been formed instead of a fault trough." According to the writer's hypothesis, the Farnham dome, as mapped at the surface, might simply represent a deeper phase of a graben-and-horst structure than the other domes in Utah where the "graben phase" is intersected by the present surface. This, of course, is not a justifiable conclusion for the structure of the Farnham dome but is a hypothesis to be considered.

NORMAL FAULTS IN AUSTIN CHALK

The Austin chalk in Dallas County, Texas, is cut by many small, normal faults. Displacements generally range from a few inches to 5 feet although some up to ten feet have been reported. These faults do not appear to go down into the underlying Eagle Ford shale any appreciable distance.[16] Grabens, horsts, and intersecting systems of fractures are present. Figure 5[17] shows a graben located in the crest of a small anticline, and Figure 6[18] is a sketch of a horst in the Austin chalk by Shuler. The point of convergence of the faults is below the surface in the graben and at the top of the escarpment in the horst. We can not determine, therefore, whether or not these are parts of graben-and-horst structures. Figure 7, however, is a photograph of a system of faults which does show the zone of intersection. Although displacements along all planes, except the one dipping toward the right, are small, a clearly defined graben on the right of the large fault is in juxtaposition with a horst left of the main fault, and the probable relationship between this structure and those illustrated in Figures 5 and 6 is obvious. Shuler[19] states that in some areas in the Austin chalk "horst and graben structures alternate in rapid succession." The faults in these areas are only 50–100 feet apart, and the dip of the fault planes ranges from 45° to 60°. As already stated, these faults do not generally involve the underlying Eagle Ford shale, and it is, therefore, not possible to make a study in sufficient depth to determine whether or not these closely spaced grabens and horsts are separate

[14] Stephen Taber, "Fault Troughs," *Jour. Geol.*, Vol. 35, No. 7 (1927), pp. 581–90.

[15] *Ibid.*, p. 588.

[16] Dallas Petroleum Geologists, "Geology of Dallas County, Texas" (December, 1941), p. 67.

[17] *Ibid.*, p. 68.

[18] Ellis W. Shuler, "The Geology of Dallas County," *Univ. Texas Bull. 1818* (March, 1918), p. 21.

[19] *Ibid.*, p. 22.

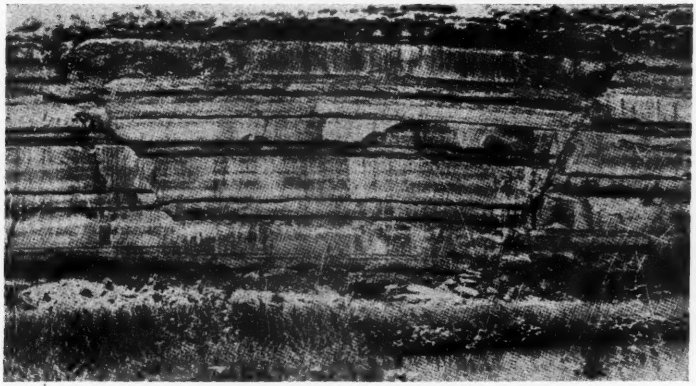

FIG. 5.—Small graben in Austin chalk, quarry of Trinity Portland Cement Company, Dallas County, Texas.

structures or simply the zone of intersection of a large multiple-fault graben-and-horst structure. Figure 8 shows how a group of grabens and horsts could be inter-

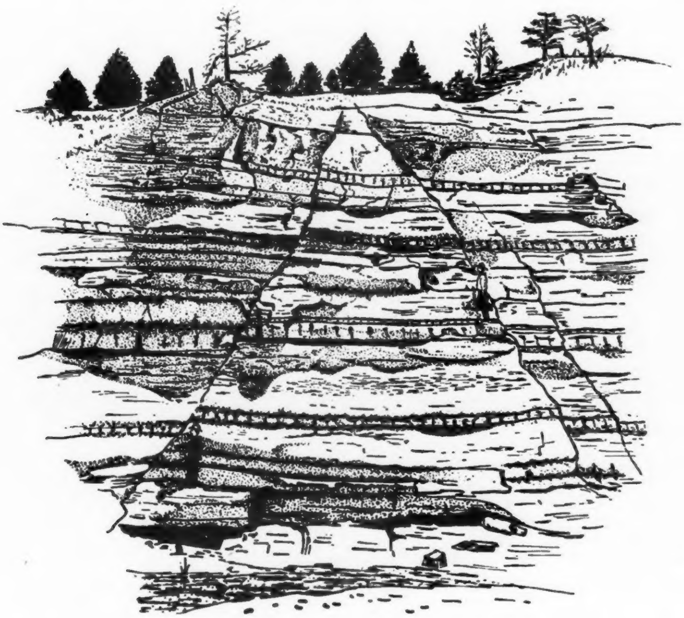

FIG. 6.—Sketch of horst in Austin chalk on Cedar Creek, Forest Park, Dallas County, Texas.

preted as parts of a single structure. Failure to find the horst phase developed in the underlying Eagle Ford shale may be due to yielding of the shale by plastic flow or to the possibility that the Austin faulting is related to surface irregularities at the top of the Eagle Ford. If this is true, the faulting is probably related to

FIG. 7.—Intersecting faults in Austin chalk, Turtle Creek, Dallas, Texas.

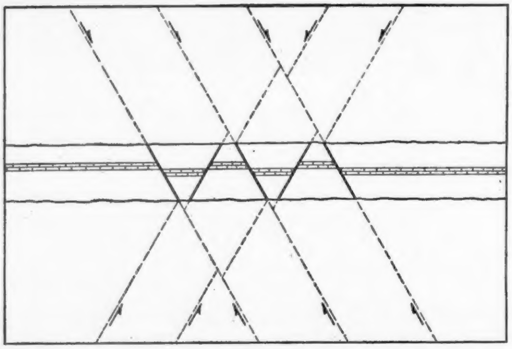

FIG. 8.—Cross section showing how group of closely spaced grabens and horsts may be resolved into single multiple-fault graben-and-horst structure.

"lows" and "highs" of very low relief in the shale. It has been suggested[20] that differential compaction in the Eagle Ford may have given the relief at the Austin-Eagle Ford contact which, in turn, caused the faulting in the overlying beds. Whatever the origin of the forces causing the faulting in the Austin chalk, the pattern in places resembles that of graben-and-horst structures.

[20] Dallas Petroleum Geologists, *op. cit.*, p. 69.

CONCLUSIONS

From the foregoing data, two generalizations are apparent. The first of these is a well established principle subject to wide application. The second is one of three possible fault patterns to be considered wherever grabens are present in uplifted areas.

1. *Grabens may be formed over intrusions or in other structural uplifts as a result of tensile or shearing stresses in the upfolded rock mass.*

Although grabens cutting across domes are common in the Gulf Coast, little effort appears to have been made to apply this principle to broader fields of structural geology. The writer believes that recognition of vertical movements as a cause of grabens will be of value in structural interpretation in many areas.

2. *The faults of grabens in uplifted areas may cross and form a horst beneath the graben.*

As previously stated, three possibilities exist wherever graben faulting is present: (1) both faults may terminate in depth at or above the line of convergence, (2) one fault may continue in depth while the opposing one terminates against the first, and (3) the faults may cross and form a graben-and-horst structure. Consideration has heretofore been limited largely to the first two alternatives. Little consideration has ever been given to the third.

That grabens are found in salt domes and in domes which probably contain salt plugs at great depth can scarcely be denied. In a salt dome of the Cheneyville type where two or more faults of large throw are present directly over the apex of the salt, a horst, involving at least the salt plug and a block of sediment over the plug is implied. A photograph of intersecting normal faults is given in Figure 7.

If the same conditions of lithology and stress are present below the graben as in the beds where graben faulting is observed, then the formation of a horst below the graben is very likely since horst faulting gives the same relief to stresses that graben faulting does. Conditions of stress can, of course, change with depth as they do in isoclinal folds. In this type of fold, grabens could develop in the most severely stretched zone and rock flowage occur in the area below the graben between the vertical or nearly vertical limbs of the anticline. However, faulting in the areas previously described as involving, or possibly involving, graben-and-horst faulting is in folds of the open type where conditions of stress under the graben are not likely to be greatly different from those in the graben area itself.

Different kinds of stresses have frequently been assumed for grabens and horsts in the literature of structural geology. Actually they may be parts of a single structure, formed simultaneously by the same forces. Surface exposures give only a limited view of fault structures, and data from oil wells are limited to less than three miles in depth. This condition has given us only localized pictures of structures and has led us to the assumption that grabens and horsts

are complete structural units. In some cases this is not true. Much is to be gained by consideration of the possible presence of a larger structural unit, of which a graben or horst may be only a part or segment.

RIFT VALLEYS

Outstanding among all grabens in the earth's crust are, of course, the rift valleys. Without subsurface data about these areas, the nature of the structure beneath the surface as well as the origin of the rifts are subjects upon which there is little agreement. Certain facts are apparent from surface and geophysical data, however. 1. Most rift valleys cut through mountains, high plateaus, or other areas of pronounced uplift. 2. Igneous extrusions are generally associated with rift valleys. 3. Gravity data indicate an excess of light matter beneath rift valleys. 4. Rift valleys are bounded on either side by nearly parallel faults. Most but not all investigators agree that these master faults are normal. The rift valleys of Africa transect the highest plateaus of the continent, and volcanic rocks are scattered throughout a great part of the faulted areas. Furthermore, gravity data indicate that the African rifts are underlain by an excess of light material.[21] Similar conditions prevail in the Rhinegraben where mountains flank the rift on either side.

The presence of grabens in uplifted areas is thus common to both rift valleys and to certain of the Gulf Coast oil-field structures. Lacking subsurface data on

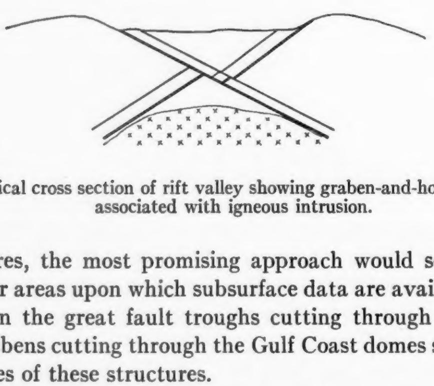

FIG. 9.—Hypothetical cross section of rift valley showing graben-and-horst structure in uplift associated with igneous intrusion.

rift valley structures, the most promising approach would seem to be a comparison with similar areas upon which subsurface data are available. The tectonic similarities between the great fault troughs cutting through elevated plateaus and the smaller grabens cutting through the Gulf Coast domes suggest similarities in the deeper phases of these structures.

The presence of extrusives in the elevated regions through which the rifts cut suggests the possibility that the great uplift might have been caused by deep-seated igneous intrusion. This condition would be parallel with the graben-and-horst faulting over the salt intrusions of the Gulf Coast. Figure 9 is a hypothetical cross section showing how a rift valley might thus be formed over an igneous intrusion.

[21] Reginald Aldworth Daly, *Strength and Structure of the Earth* (1940), pp. 218–24.

It is also possible, however, that the uplift took the form of a great bulging of the crust without excessive intrusion of igneous material as illustrated in Figure 10. Stretching of the crust over the bulge could cause graben-and-horst faulting without intrusion just as such faulting has occurred in some Gulf Coast anticlines where salt intrusion has not been observed. In this case, the zone of intersection of the faults could be located deeper in the crust than in the case of igneous intrusion. A large part of the "horst phase" of the structure could, in fact, be lost in the zone of flow below the crust just as the lower phase of the fault systems of the Austin chalk are lost in the less brittle underlying Eagle Ford shale.

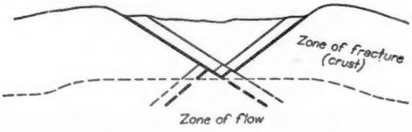

FIG. 10.—Hypothetical cross section of rift valley showing graben-and-horst structure in uplift without associated igneous intrusion. Part or all of "horst phase" may be lost in zone of flow beneath crust.

A graben-and-horst structure is consistent with gravity data on rift valleys. The indicated excess of light material would cause a rise of the rock mass under the usual interpretation of isostasy. As previously stated, it does not matter whether this rise was primarily of an intrusive nature or primarily a great upbulging of the crust with intrusives playing only a minor role. In either case, graben-and-horst faulting could develop in the uplift, the rift valley being only the superficial and exposed phase of the structure. Some geologists have expressed difficulty in reconciling a downdropped block with gravity data which indicate an excess of light matter beneath and a consequent tendency for upward movement. Because it seemed that some mechanism was required to "hold down" the fault block against the upward hydrostatic forces operating, reverse faulting under horizontal compression was postulated. Since graben-and-horst faulting is consistent with uplift, no such mechanism for holding down the graben block is needed.

The foregoing remarks on rift valleys are offered only as a working hypothesis, and no attempt is made to prove or disprove it. It is believed, however, that comparison of rift valleys with the Gulf Coast oil-field structures described offers an approach to the problem of the subsurface structure and origin of rift valleys that has heretofore received little attention.

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GEOLOGICAL NOTES

INTERESTING WILDCAT WELLS DRILLED IN NORTH LOUISIANA IN 1942[1]

B. W. BLANPIED[2] AND ROY T. HAZZARD[2]
Shreveport, Louisiana

BOSSIER PARISH, BELLEVUE FIELD

The Phillips Petroleum Company's Kendrick well No. 1, Sec. 22, T. 19 N., R. 11 W., in the Bellevue field, was completed as a dry hole, in salt, in October, 1942, with total depth of 9,070 feet; top of the salt was encountered at 9,046 feet.

The Bellevue structure is interesting from the standpoint of the structural and sedimentary geology of the North Louisiana area. The growth of this structure is reflected in the subsurface of the Tertiary and of the Upper and Lower Cretaceous, with deformation increasing in intensity with depth. Interpretation of the stratigraphic and structural data indicates that the Bellevue area was subjected to at least three distinct periods of domal uplift, and, additionally, there is stratigraphic evidence that the dome was growing slowly during deposition of the Cretaceous and Tertiary.

Following is an interpretation of the formational contacts encountered in the Kendrick well. Top Saratoga chalk, 710 feet; base of Annona chalk, 990 feet; Buckrange sand (basal Taylor), 1,140–1,168 feet; top Austin, 1,168 feet; top first sand in Tokio, 1,219 feet; base of Austin (base northerly feather-edge of the Ector tongue), 1,780 feet; top Eagle Ford, 1,780 feet; basal beds of Eagle Ford age, the Lewisville volcanics, made up of variegated shales and tuffaceous sands, 1,830–1,878 feet; Upper Cretaceous-Lower Cretaceous contact, 1,878 feet; with the Lewisville volcanics resting on lower Glen Rose; top Three-Finger limestone, 2,462 feet, top Hosston, 2,760 feet; top upper Cotton Valley (Lower Cretaceous-Jurassic contact), 4,840 feet; top of "D" sand?, 5,385 feet; top Bodcaw sand?, 5,480 feet; top of lower Cotton Valley, 6,525 feet; base of lower Cotton Valley, 8,160 feet; top of Smackover limestone, 8,160 feet; top of salt, 9,046 feet.

R. W. Imlay of the U. S. Geological Survey has recognized Lower Kimmeridgian and Upper Oxfordian (Argovian) ammonites in cores between depths of 8,000 and 8,800 feet.

The basal Upper Cretaceous beds in the Kendrick well rest on limestones of lower Glen Rose age. In comparison with wells drilled in the general area, the Paluxy, upper Glen Rose, Ferry Lake (massive) anhydrite, and approximately 200 feet of the upper part of the lower Glen Rose were removed from the Bellevue uplift during the erosional period between Upper and Lower Cretaceous deposition. Two wells northeast of the Bellevue uplift, and south of the Cotton Valley field, encountered a section of Washita and Fredericksburg. These post-Trinity Lower Cretaceous beds probably had a wide extent in Louisiana and Arkansas, north and east of Bellevue and were stripped during the period in which an estimated 2,000 feet of Trinity beds were eroded from the Bellevue uplift.

Available subsurface information indicates that the Bellevue structure is intricately faulted in the Upper Cretaceous. The possibility of numerous faults in depth, and the absence of beds with the lithologic characteristics of the Buckner and of the oölitic limestone back-reef facies of the Smackover limestone, make it difficult to determine the top of the Smackover limestone in the Kendrick well. This difficulty is due to the lithologic

[1] Read by title before the Association at Fort Worth, April 7–9, 1943. Manuscript received, December 4, 1943.

[2] Gulf Refining Company.

similarity of sediments of the lower Cotton Valley and of the fore-reef facies of the Smackover limestone. The lithologic character of cuttings and cores between 8,660 and 9,055 feet indicates that this interval is comparable with the lower part of the Smackover limestone section encountered in deep wells in the North Lisbon field. The basal 40 feet is interbedded gray banded dolomite and fine granular dolomite and dark shale. Cores did not show perceptible dips.

Certain regional stratigraphic and structural features must be considered before attempting an interpretation of the Jurassic section in the Bellevue well and in several deep wells drilled on the Sabine uplift.

Drilling in South Arkansas, North Louisiana, and Texas has shown that the deposition of the Buckner occurred in a broad zone, extending from eastern Louisiana westward into Texas as far southwest as Limestone County. The east and southwest limits of the zone are not known but its inner edge approximately parallels the periphery of the Smackover limestone basin. Maximum width of the zone of Buckner deposition as now known is nearly 60 miles. The Buckner formation is approximately 300 feet thick in a deep well drilled in the southwest part of the North Lisbon field. Its presence out beyond the postulated barrier reef marks a southward regression of the Smackover limestone sea. During the regression, an interfingering sequence of lagoonal beds, with anhydrite and red shale, and shallow-water marine deposits was laid down. The Buckner overlies both the back-reef and fore-reef facies of the Smackover limestone. Lack of deep-well control makes it impossible to be certain of the regional continuity of the Buckner lagoonal deposits in the zone paralleling the periphery of the Smackover limestone basin. Whether or not Buckner deposition was interrupted by broad promontories extending out into the basin is a matter of conjecture. Changes in facies of the Buckner could be expected over uplifts of the sea bottom.

Since several of the deep wells under consideration are on the Sabine uplift, it is necessary to define the usage of the term. The Sabine uplift is the broad uplift between the North Louisiana and the East Texas downwarps. Its north extent is limited by the Cass County syncline which trends eastward from Cass County, Texas, into southwestern Arkansas. Its south limit is the Angelina-Caldwell flexure. Its outline on the surface is approximated by the outline of the Tertiary Claiborne-Wilcox contact. Within its subsurface extent the uplift is modified by faults, local domal uplifts, and downwarps. Rodessa, an elongate fault structure, is on the north edge. In Louisiana, Pine Island, Shreveport, Sligo, Elm Grove, and DeSoto-Red River are localized structures, superposed on the major regional structure. The Waskom-Bethany and Logansport structures are located along the state line. The East Texas field lies on the west flank.

Dependent on interpretation of well data, the Sabine uplift appears to have been a positive element during Upper Cretaceous deposition. All the previously named localized structural features on the Sabine uplift have a pre-Upper Cretaceous period of deformation. It is reasonable to assume that the upwarp of the Sabine uplift, three stages of which are recognized, is related to movements in the underlying basement rock, and if this is true, periods of pre-Lower Cretaceous upwarp may have occurred. The lack of typical Buckner deposits in certain deep wells on the Sabine uplift is most easily interpreted as due to faulting, with the possibility that facies change or non-deposition may account for the non-appearance of the typical lithologic features. In light of the conception that older pre-Lower Cretaceous movements may have occurred, the possible existence of a post-Buckner-pre-Lower Cotton Valley erosion period must not be eliminated, particularly if the local uplifts on which the wells were drilled are known or suspected to be non-faulted structures.

Table I shows the writers' interpretation of the Jurassic sections in three wells on local structure on the Sabine uplift, in comparison with the sections at Bellevue, at North Lisbon, and in a deep well in Lafayette County, Arkansas.

TABLE I

	The Texas Co., Adams No. 1, Thomas Cox Hrs., Panola Co., Tex. Bethany	*Stanolind O. & G. Co., Dillon Hrs. No. 131, 14-21N-15W, Caddo Ph., La. Pine Island*	*R. W. Norton, Payne No. 1, 27-23N-16W, Caddo Ph., La. Rodessa*	*Phillips Pet. Co., Kendrick No. 1, 22-19N-11W, Bossier Ph., La. Bellevue*	*Union Prod. Co., McDonald No. 1, 13-21N-5W, Claiborne Ph., La. North Lisbon*	*McAlester F. O. Co., Jeffus No. 1, 4-19S-23W Lafayette, Ark.*
		Sabine uplift		Salt uplifts in Fore-Reef basin		In Back-Reef basin
Elevation in feet above sea	287	237	222	231	323	260
		Depth in Feet below Sea-Level				
Top Upper Cotton Valley	−7,488	−5,698	−7,868	−4,609	−7,169	−7,400
Top Lower Cotton Valley	−8,993	−7,383	−9,733	−6,294	−9,262	−9,595
Base Lower Cotton Valley	−10,178	−8,803	−10,098	−7,929	−11,147	−9,968
Top Buckner	Not present	Not present	Not present	Not present	−11,147	−9,968
Top Smackover limestone	−10,178	−8,803	−10,098	−7,929	−11,480	−10,132
Base Smackover limestone	−10,718	−9,848	−11,183	−8,762	−13,097 Est.	Not reached Est. below −10,800
Top salt	−10,780	−9,922	−11,248	−8,815	−13,157 Est.	Not reached Est. below −10,840
		Thicknesses				
Upper Cotton Valley	1,505	1,685	1,865	1,685	2,093	2,195
Lower Cotton Valley	1,185	1,420	365	1,635	1,885	373
Buckner	Not present	Not present	Not present	Not present	333	164
Smackover limestone	540 (eroded)	(1,045 eroded)	(1,085 eroded)	833 (eroded)	1,615 Est. (Normal)	85 penetrated (Probably normal)
Clastics above salt	62	74	65	53	60 Est.	—

Detailed correlations of electrical-log markers in the Jurassic may be made between the Texas Company, Stanolind, Norton, and Phillips wells. These correlations do not indicate faulting within the Smackover limestone sections in these wells. The top of the Smackover limestone might be interpreted as a fault contact to explain the variations in the thickness but here again the electrical-log correlations of the basal part of the lower Cotton Valley make the fault interpretation difficult to accept.

The interpretation of the details of the tabulation are summarized as follows.

The McAlester well in Lafayette County, Arkansas, northeast of the wells on the Sabine uplift, has a longer Upper Cotton Valley section than the three wells on the uplift. This is indicative of pre-Lower Cretaceous (post-Jurassic) uplift and erosion of a part of the area of the Sabine uplift.

The McAlester well and Norton's Payne well in Rodessa have short lower Cotton Valley sections, suggestive of pre-Upper Cotton Valley erosion.

The lower Cotton Valley section of the Stanolind well at Pine Island is approximately 4 times thicker than the section in Norton's Payne well, which indicates a pre-Upper Cotton Valley movement along the Rodessa fault, with downthrow on the south.

There is no proof that a pre-Lower Cotton Valley (post-Buckner) period of erosion existed. The most tenable hypothesis, to the writers, to account for the absence of typical Buckner in the deep wells on the Sabine uplift and in the Kendrick well at Bellevue is the erosional hypothesis. If this hypothesis is accepted, the uplifts of Bethany and Bellevue were greater in amount than those at Pine Island and Rodessa, as measured in the amount of stripping of sediments. The upper 400 feet of the Smackover limestone in the Norton well at Rodessa was characterized by oölitic limestone of the back-reef facies; the lower part is typical of the fore-reef facies. The Smackover limestone of the Pine Island, Bellevue, and Bethany wells is of the fore-reef facies; whether or not oölitic limestones were present in the eroded sections is conjectural. On the assumption of 1,400 feet for the original combined thickness of the Buckner and Smackover limestones, the post-Buckner erosion at Bethany approximates 800 feet; at Bellevue, more than 500 feet; and at Pine Island and Rodessa, more than 300 feet.

Several interpretations may be made of the stratigraphic relationships of beds below 8,100 feet in the Kendrick well. From study of cutting, core, and electrical-log records and consideration of the regional subsurface geology it is the writers' opinion that the top of the Smackover limestone occurs at 8,160 feet and that the upper part of the Smackover limestone and the Buckner formation were eroded before deposition of the lower Cotton Valley. Compared with the thickness of the Smackover limestone of the fore-reef facies at North Lisbon, Claiborne Parish, and with the Smackover limestone in Rodessa, Caddo Parish, the shortened Smackover limestone in the Kendrick well might be attributed to erosion, faulting, non-deposition, or salt intrusion into the basal part of the formation. Of these four possibilities, only the last may be eliminated by stratigraphic evidence.

Cuttings of medium to coarse conglomeratic sand were reported between 9,040 and 9,050 feet in the Kendrick well, between the base of the limestone and the top of the salt. Elsewhere in South Arkansas, North Louisiana, and East Texas, 20–60 feet of sediments, in part reddish and gray sands and shales, occur between the base of the limestone and the top of the salt; therefore, it is reasonable to believe that the conglomeratic sand cuttings from the Kendrick well actually represent a bed of this horizon. In light of available information, it is the writers' opinion that the relation between the basal Smackover limestone and the salt in the Kendrick well is normal, with the clastics below the base of the Smackover limestone resting on salt. It appears that the growth of the Bellevue dome to its present structural position did not involve the intrusion of the salt into the sedimentary beds directly overlying it.

Correlation of the electrical logs of the Stanolind and the Phillips wells shows a progressive shortening of the intervals between a sequence of electrical log markers in the Phillips well, upward from the base of the Smackover limestone. It is the opinion of the writers that these shortened intervals in the Phillips' Kendrick well are due to progressive uplift during deposition of the lower part of the Smackover limestone; a fault hypothesis to account for these shortened intervals would necessitate the presence of three faults of relatively small throw.

Several prominent structural features in North Louisiana are present in the fore-reef basin south of the postulated barrier reef (see discussion of Hunt's Mitchiner well in the East Haynesville area). On two of these structures, Bellevue and North Lisbon, deep wells have been drilled into salt. On both structures, it appears that the salt has not intruded into the basal part of the Smackover limestone although the uplifts on the top of the Smackover limestone may be as great as 1,000 feet.

North Lisbon, Sugar Creek, Homer, Bellevue, and Sligo are prominent faulted domal structures which on some key horizon show an approximately circular outline. All have appreciable uplift at some depth. Of this group, Homer and Bellevue show the greatest amount of uplift in the Lower Cretaceous beds. The origin of these circular domal structures must be attributed to an upward vertical force. Whether the salt is the active agent in causing the deformation, or whether it is a passive factor in the Bellevue structure, may be determined from the writers' interpretation of its geological history.

1. Smackover limestone and Buckner sedimentation followed by uplift and local truncation of uplifted beds.
2. Cotton Valley and Lower Cretaceous sedimentation followed by uplift and local truncation of uplifted beds.
3. Upper Cretaceous and Tertiary sedimentation followed by uplift and local truncation of uplifted beds.

The foregoing sequence of events may be presented in footage of sediments.

	Footage Sedimentation		*Footage Erosion*
(1)	1,500 plus	Uplift	500 plus
(2)	6,000 plus	Uplift	2,000 plus
(3)	3,000 plus	Uplift	1,000 plus

The latest dating of the uplift of the Bellevue dome is post-Claiborne; it actually may be considerably later.

For the case of a sedimentary basin underlain by a salt deposit of considerable thickness, which has not been subjected to regional compressive forces, of any magnitude, it appears that the salt may remain static until a critical sedimentary loading factor has been exceeded.

In localized areas in which there exist variations in the thickness of the salt due to its depositional enviroment or variations in thickness due to movements in the basement rocks below the salt, a pressure differential exists at some zone within the salt due to the difference in weights of adjacent rock columns. At some stage during sedimentation, lateral movement of salt takes place, simulating plastic flowage directed toward an area of lesser pressure. An upward bulge or breakage in the continuity of the upper salt surface would be a favorable area for the initiation of growth of the salt column. Upward movement of the salt ceases when the energy is expended in raising the overburden and overcoming friction. Once initiated, subsequent stages in the cycle may be repeated following later sedimentary periods.

Bellevue and North Lisbon appear to represent different stages in the cycle of domal growth. The major faulting associated with the growth of the North Lisbon Smackover limestone structure does not go above the base of the upper Cotton Valley (an unconformity). Minor faulting occurs in the upper Cotton Valley below the Lower Cretaceous-Jurassic contact (an unconformity). The growth of the Bellevue dome contrasted to that of the North Lisbon dome has three definite stages. Deep drilling may show that Homer is similar to Bellevue in many respects. The greater uplift at Homer indicates a greater salt movement and it may be that actual salt intrusion into the Smackover limestone has taken place.

The elongate domal structures such as Cotton Valley and Bistineau are thought to be comparable in origin with the circular domal structure. Subsurface studies of the Cotton Valley field show that the uplift is in three stages, which are separated by major unconformities.

CLAIBORNE PARISH, EAST HAYNESVILLE AREA

In February, 1942, the Hunt Oil Company's Mitchiner No. 1, Sec. 15, T. 23 N., R. 7 W., elevation 267 feet (derrick floor), was abandoned at 11,255 feet in salt after penetrating approximately 300 feet of beds which may be correlated with the upper part of the Smackover limestone. The Mitchiner well is approximately 6 miles east of the Ohio's Taylor No. 15, Sec. 15, T. 23 N., R. 8 W., an 11,274-foot Smackover limestone test in the Haynesville field in 1940.

Formational contacts in Hunt's Mitchiner well were logged at the following depths: top Upper Cretaceous, 1,920 feet; top Nacatoch sand, 2,038 feet; top Saratoga chalk, 2,302 feet; base Annona chalk, 2,598 feet; base Tokio (base Austin) and top Eagle Ford shale, 3,195 feet; Lewisville volcanics, 3,340–3,413 feet; Upper Cretaceous-Lower Cretaceous contact, 3,413 feet; base Ferry Lake (massive) anhydrite, 4,086 feet; top James limestone, 4,650 feet; top Hosston, 5,260 feet; top upper Cotton Valley (base Hosston), 7,060 feet; top lower Cotton Valley, 9,065 feet; top Buckner, 10,485 feet (-10,218); top Smackover limestone, 10,885 feet (–10,618); top salt, approximately 11,200 feet, with core of salt between 11,235 and 11,255 feet.

Cutting and electrical-log records of the Mitchiner well show that the lower Cotton Valley, Buckner, and the upper 300 feet of the Smackover limestone are comparable in thickness and lithologic character with the same units in the Ohio's Taylor well in the Haynesville field, to its total depth. Top of the Buckner formation was encountered at 10,550 feet (–10,212) and top of Smackover limestone at 10,957 feet (–10,619) in the Taylor well, making the Mitchiner and Taylor wells level structurally on top of the Buckner

and Smackover limestones. Approximately 315 feet of Smackover limestone was penetrated in both wells, although salt was not encountered in the Taylor well at its total depth of 11,274 feet. The Buckner and Smackover limestone contacts in the two wells appear to be normal contacts. The foregoing interpretation of the sequence does not conform with the current opinion that the Smackover limestone of the Mitchiner well is the basal part of the Smackover limestone which normally occurs above the salt in the North Lisbon field, which is approximately 20 miles southeast of the Mitchiner well, in eastern Claiborne Parish.

The comparable sub-sea depths on the top of the Buckner and Smackover limestones in the two wells, and the similar Buckner and Smackover limestone sections and their contact relationships, preclude the presence of a sharp domal uplift of the Buckner and Smackover limestones in the Mitchiner well alone, without a similar uplift underlying the Taylor well. Salt intrusion into the Smackover limestone of the Mitchiner well, if it actually did occur, necessarily would be pre-upper Smackover limestone in age, and not post-Smackover or post-Buckner, if the Taylor well is considered to have a normal stratigraphic section to its total depth and to be a normal well structurally. The Smackover limestone-salt contact in the Mitchiner well may be interpreted as a fault contact; compared with the Taylor well 6 miles west, the Mitchiner well may have encountered the top of the Smackover limestone on the downthrown side of a fault and passed into salt on the upthrown side.

There is insufficient information on which to base a definite statement whether or not the Smackover limestone-salt relationship in the Mitchiner well is structural or stratigraphic. The following possibilities are pointed out: (1) salt lenses in the Smackover limestone, (2) fault relationship, (3) intrusive relationship, (4) abnormal stratigraphic relationship.

1. *Salt lenses.*—The occurrence of salt lenses 300 feet below the top of the Smackover limestone has not been recorded to date in deep wells drilled in South Arkansas and North Louisiana.

2. *Fault relationship.*—Abnormal structural and stratigraphic conditions encountered in deep wildcat wells are most easily explained on the assumption that faulting has occurred, and in many places, additional drilling confirms the first assumption. The Smackover limestone-salt contact in the Mitchiner well, if due to faulting, would require a fault with magnitude between 500 and 1,300 feet depending on the assumed thickness of the Smackover limestone. Faults of this magnitude are known in the subsurface of South Arkansas and North Louisiana, and from the present deep well control in Claiborne Parish, Louisiana, and in Union and Columbia counties, Arkansas, a fault, with any strike desired by the interpreter, may be assumed in the East Haynesville area. In light of available geophysical information, the writers, however, consider the fault hypothesis untenable.

3. *Intrusive relationship.*—The character of the North Lisbon structure, eastern Claiborne Parish, as contoured on the top of the Smackover limestone, and on top of the salt, indicates that this faulted structure may mark an incipient stage in salt-dome growth, with no actual salt penetration into the basal part of the overlying Smackover limestone. The short section of approximately 300 feet of Smackover limestone in the Mitchiner well, compared with the estimated 1,615 feet of Smackover limestone equivalent in the North Lisbon field, may be fairly good evidence that the relationship found in the Mitchiner well indicates a localized salt intrusion into the basal part of the Smackover limestone.

4. *Abnormal stratigraphic relationship.*—It is the writers' opinion that another logical hypothesis may be offered for the Smackover limestone-salt relationship in the Mitchiner well, which is that of an abnormal stratigraphic relationship. The usage of the term "abnormal" means that the stratigraphic relation, which is dependent on structure, heretofore has not been recognized in the Arkansas-Louisiana Jurassic salt basin.

A regional structural feature, the axis of which approximates the Louisiana-Arkansas state line from west to east a distance of 35–40 miles, may be noted in the subsurface of the areas adjacent to the state line. This feature is the North Carterville-Haynesville-East Haynesville anticlinal trend, the alignment and outline of which are easily appreciated on regional contour maps, using the base of the Ferry Lake (massive) anhydrite as datum. In part, it is still visible on regional contour maps made on the base of the Annona chalk as datum. On the north, and more or less parallel with the anticlinal trend, is a regional synclinal trend. The anticlinal trend extends from T. 23 N., R. 12 W., to T. 23 N., R. 5 W., in Louisiana.

It is visualized that a salt swell or salt anticline 40 miles in length from west to east, existed in the early Smackover limestone sea, forming a reef-like structural barrier, the top of which was at shallow depth throughout Smackover limestone deposition. Inside and landward from the barrier were deposited the back-reef non-oölitic and oölitic limestones. Across the top of the barrier, in late Smackover time, interfingering of back-reef and fore-reef deposits took place. The thick fore-reef deposits, made up of dark shales, dark limestones, and fine sands, are found at North Lisbon overlain by a relatively thin development of a shaly back-reef limestone deposit. Source of the fore-reef sediments appears to have been on the east, in part, and not across the reef. The deposition of the back-reef facies of the Smackover limestone, which is characterized by a lack of terrigenous sediments, was controlled by the continuous upgrowth of the salt anticline to a depth near existing sea-level, and the cutting-off of a peripheral part of the basin during the regional downwarp of the whole basin. The thickness of the Smackover back-reef facies may be two or three times as great as the thickness of the Smackover limestone across the crest of the anticline, due to the downwarp of the back-reef basin while the crest of the salt anticline remained relatively static, as referred to existing sea-level.

The North Carterville-Haynesville-East Haynesville structural trend, seen in the subsurface of the Upper and Lower Cretaceous beds, is interpreted as resulting from the continuance of the deeper movements along the buried trend of the salt anticline.

The usage of the term "salt swell" or "salt anticline" carries no connotation that the Jurassic salt was an active agent in the development of the barrier reef. It is thought that the salt anticline came into existence early during Smackover time with a minimum thickness of clastic cover overlying the salt in the areas both north and south of the barrier reef.

The prominent elongate anticlinal structures in the back-reef basin such as Schuler, Magnolia, Dorcheat-Macedonia, McKamie, Buckner, and Midway, are considered to be manifestations of the same type of basement-rock movements as that which gave rise to the older barrier-reef structure. It is the writers' opinion that the regional west-to-east trends of the barrier reef and of the younger back-reef basin structures are inherited from basement-rock structures which may be of the age of the Ouachita Mountain folding.

No direct evidence is available that the salt, which underlies the elongate anticlinal structures in the back-reef basin, was either an active or a passive factor in the deformation of the Buckner and Smackover formations. These structures appear to have originated before the lower Cotton Valley was laid down. The thickness of sediments above the salt when the first period of folding took place was probably less than 1,200 feet. Lithologic variations of the upper part of the Smackover limestone, between wells on and off structure, suggest very shallow reef conditions along the crests of the anticlines, indicating local minor warping of the sea bottom. Loading imposed by the deposition of the uppermost Jurassic, Cretaceous, and Tertiary sediments may have been sufficient to induce some salt flowage in the back-reef basin structures, at periods subsequent to the original folding.

It has been reported that interpretation of geophysical surveys indicates that the Mid-

way structure in Lafayette County may not be underlain by salt, or, if present, may be very thin. There is some evidence that older Jurassic beds, which may be thick, underlie the salt in Arkansas and probably in Louisiana. The uplift of the Midway structure, if no salt is present, must be dependent on movements in the basement rocks transmitted through the pre-salt Jurassic beds. The Midway structure is one of the group of the structures in the back-reef basin, and conceivably, the presence or absence of salt has no relation to its origin.

The Jurassic salt which underlies the Smackover limestone has been correlated with the Eagle Mills redbeds. There is some evidence to indicate that the Eagle Mills is older than the salt. Tentatively, it is assumed that the Eagle Mills is Jurassic in age and that it is not the time equivalent of the Paleozoic section encountered in a deep well in Morehouse Parish, Louisiana.

The nomenclature and stratigraphic sequence presented in the following correlation table are tentative, and may not be usable in the light of knowledge to be gained from future deep drilling.

- Jurassic
  - Cotton Valley
    - (*Unconformity*)
  - Buckner
  - Smackover limestone
    - Back-reef and fore-reef facies
  - Norphlet salt
    - With redbed tongue above salt
  - Werner anhydrite
  - Eagle Mills
    - (*Unconformity?*)
- Paleozoic

SALT-DOME DISCOVERIES IN NORTH LOUISIANA IN 1942[1]

B. W. BLANPIED[2] AND ROY T. HAZZARD[2]
Shreveport, Louisiana

Three piercement-type salt domes were discovered during the year, two of which are in Madison Parish and one in Tensas Parish. The Tullulah dome, in Madison Parish, is in the southeast part of T. 16 N., R. 12 E., 7½ miles northeast of the Singer dome. The Coleman dome, in Madison Parish, is in the southwest part of T. 15 N., R. 13 E., 11 miles southeast of the Singer dome. The Tullulah and Coleman domes are 6 miles apart. The Ashwood dome, in Tensas Parish, is in the southeast part of T. 14 N., R. 11 E., 6½ miles northwest of the Newellton dome. One test on the Newellton dome, in the southwest part of T. 13 N., R. 12 E., was drilled during the year.

Following is a summary of the 1942 developments on the three newly discovered salt domes and on the Newellton dome.

COLEMAN DOME, MADISON PARISH

The Continental Oil Company drilled two tests on a geophysical prospect in the southwest part of T. 15 N., R. 13 E. The first test, Watts No. 1, in irregular Sec. 40, T. 15 N., R. 13 E., penetrated calcite cap rock and lost drilling returns; it was abandoned in calcite cap rock, June 3, 1942, at the total depth of 3,387 feet. The top of the calcite cap rock was

[1] Read by title before the Association at Fort Worth, April 7–9, 1943. Manuscript received, December 4, 1943.

[2] Gulf Refining Company.

encountered at 3,352 (−3,263) feet. The second test, Watts No. 2, was on the flank of the dome in irregular Sec. 41, T. 15 N., R. 13 E., ½ mile southwest of Watts No. 1; it was abandoned in Midway shale, July 14, 1942, at 5,447 feet. Structurally, on top of the Wilcox, the flank test is 232 feet lower than the cap-rock test. The thickness of the Wilcox in Watts No. 1, the cap-rock test, was 626 feet; in the flank test, 2,372 feet. The thickness of the Claiborne in Watts No. 1 was 1,936 feet, which may be a faulted section. Survey of Watts No. 2, the flank test, ended below the top of the Cockfield so that the full Claiborne thickness is not known.

TULLULAH DOME, MADISON PARISH

The Continental Oil Company's Patterson No. 1, located on a gravity prospect with its approximate center in irregular Sec. 7, T. 16 N., R. 12 E., was dry and abandoned, September 5, 1942, at the total depth of 3,043 feet, in salt. The top of the salt was encountered at 3,023 (−2,934) feet. Calcite and anhydrite cap rock were missing, and the Wilcox was directly in contact with salt. A section of 431 feet of Wilcox was encountered in the Patterson well; the Claiborne interval of 1,085 feet appears to be faulted, and much of the Cook Mountain and Cockfield formations is missing.

ASHWOOD DOME, TENSAS PARISH

The Carter Oil Company's H. Jacoby No. 1, Sec. 34, T. 14 N., R. 11 E., was dry and abandoned, July 9, 1942, at 4,400 feet, in salt. The top of the calcite cap rock was encountered at 3,994 (−3,919) feet; and top of the salt at 4,073 (−3,998) feet. The thickness of the Wilcox above the calcite cap rock was 802 feet; Claiborne thickness was 2,278 feet. At the total depth of the well, 327 feet of salt had been penetrated. No anhydrite cap was found overlying the salt.

NEWELLTON DOME, TENSAS PARISH

The Continental Oil Company's W. W. Burnside No. 1, a southeast flank test on the Newellton dome, located in irregular Sec. 70, T. 13 N., R. 12 E., was abandoned in August, 1942, at the total depth of 4,448 feet, in salt. The Burnside well was ½ mile southeast of the Continental's Cammack No. 1, discovery well of the dome, which was drilled during 1939 in Sec. 31, T. 13 N., R. 12 E.

In the Cammack well, a thickness of 1,072 feet of Wilcox was encountered with the underlying calcite cap 64 feet thick and the anhydrite cap 91 feet thick. In the flank test, the Burnside well, Wilcox thickness was 1,266 feet, calcite cap, 14 feet, and anhydrite cap, 48 feet. The Burnside well was 220 feet lower structurally on the top of the Wilcox than the Cammack well and 414 feet lower on the top of the calcite cap.

HIGHEST STRUCTURAL POINT IN TEXAS[1]

JOHN EMERY ADAMS[2]
Carlsbad, New Mexico

Occasionally erroneous statements, that are sufficiently plausible to be generally accepted and quoted, are introduced into geological literature. One of these is that the highest

[1] Manuscript received, February 11, 1944. Published with the permission of the Standard Oil Company of Texas.

[2] The Standard Oil Company of Texas.

structural point in Texas lies in the pre-Cambrian outcrops of the Van Horn uplift in Culberson and Hudspeth counties.[3]

The use of the basement complex, where available, to determine comparative structural elevations, meets with few objections, especially where the basement in both cases is known to be pre-Cambrian in age.

The determination of comparative structural elevations is a problem that may be approached from several angles. It should be clearly understood from the first, that in this paper, only present structural elevations can be considered. All structural elements of the earth's crust have a long history behind them. Some uplifts have been positive almost continuously since the beginning of known geologic time. Others have had a much shorter positive history and have been covered by much thicker sections. Obviously at some period in the past the most positive of these regions was higher than the rest, but these relations may now be reversed.

It is the general practice to map structures on key horizons. Because of possible thickness variations it should be stated in any paper making structural comparisons whether the oldest or youngest available bed, or some horizon of intermediate age, has been used to make the comparative determinations. Even when the chosen horizon is present at higher elevations on one uplift than on another the problem is not always settled. In some places the key bed has been removed from part of the uplift by erosion. If there is good evidence to assume that the missing bed originally extended across the eroded area, mapping of the reconstructed surface is justified. This is done in mapping both surface and subsurface structures. In two structures of approximately equal altitude the reconstructed horizons on one may rise higher than their completely preserved equivalents on the other. As a rule the better the regional geology is known and the more completely the section is preserved the more accurate can be the reconstructions. Where evidence indicates the probability that the missing zones lapped out against the flanks of an uplift reconstructions should of course be limited to the beds originally present. In this case the area over which the key bed was not deposited may be left blank, or the surface or structure of the underlying beds may be mapped instead. Subsurface maps substituting paleotopography for true structure are relatively common.

In those instances in which the relative stratigraphic position or age of the beds, on the two structures being compared, can not be determined, because of the lack of fossils or the lack of continuity, the problem of structural comparison may cause confusion. This is especially true in the case of the basement complex which in various parts of the world ranges from early pre-Cambrian to mid-Tertiary. In such cases the simplest method is to use some extensively recognized horizon within the complex or to regard the top of the basement as the horizon on which to contour. Here again obvious reconstructions can be made, but because of the questionable relationships and correlations such reconstructions are apt to be unsatisfactory. Certainly in the interests of intellectual honesty restorations should not be made in one region without considering the possibility of similar reconstructions in the area with which it is being compared.

By none of the methods mentioned can it be shown that the highest structural point in Texas is on the Van Horn uplift. The Upper Permian rocks of the southern Guadalupe

[3] C. L. Baker, "Exploratory Geology of a Part of Southwestern Trans-Pecos Texas," *Univ. Texas Bull. 2745* (1927), p. 41.

———," Major Structural Features of Trans-Pecos Texas," *ibid., Bull. 3401* (1935), p. 143.

———, "Rim Rock Country of Texas," *Pan-Amer. Geol.*, Vol. 75 (1941), p. 82.

P. B. King, "Outline of Structural Development in Trans-Pecos Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), p. 223.

———, "Older Rocks of the Van Horn Region of Texas," *ibid.*, Vol. 24 (1940), p. 143.

E. H. Sellards, "Pre-Paleozoic and Paleozoic Systems of Texas," *Univ. Texas Bull. 3232* (1933), p. 37.

Mountains probably attain a higher structural elevation than the same rocks had on the Van Horn uplift. But the Guadalupe Mountains are a late uplift, the stratigraphic section is much thicker, and the basement complex, which is not exposed, is thousands of feet lower than at Van Horn. From the references citing the Van Horn uplift it is apparent that the elevation of the basement complex is regarded as the real factor controlling structural interpretations. If this restriction is accepted the Guadalupe Mountains are ruled out.

The other competitor for structural honors is the Franklin Mountain uplift north of El Paso. Here the pre-Cambrian on the highest peak of the range attains an elevation of 7,152 feet, which is approximately 2,000 feet higher than the exposed top of the complex on the Van Horn uplift. So, unless a reconstructed surface can be established at Van Horn that will make this uplift much higher than it now is, the Franklin Mountains must be regarded as the highest structure in Texas.

The pre-Cambrian is not continuously exposed between the Franklin and Van Horn uplifts and therefore can not be definitely correlated. In both regions the exposed beds apparently belong in the Upper Proterozoic. The top of the pre-Cambrian is the oldest correlative horizon that can be recognized on the two uplifts. Present structure in the Van Horn region indicates that the pre-Cambrian Carrizo Mountain formation has been thrust over the pre-Cambrian Allamoore limestone and Hazel sandstone to the north. If it could be shown that the Carrizo Mountain schist were a very thick formation, that the full thickness were present at the front edge of the overthrust block, and that this thick Carrizo Mountain schist were overlain by complete sections of the Allamoore and Hazel formations, a reconstructed surface on top of the Hazel might attain a terrific elevation. But outside of the mylonite schists along the fault plane, which may indicate great pressure, we have no evidence of the weight or thickness of the overriding mass. Only a few hundred feet of Carrizo Mountain schist is preserved on the fault plane. The evidence for a thick overburden on the Carrizo Mountain is even more sketchy. King[4] has suggested that the Carrizo Mountain schist is equivalent to rather than older than the Allamoore limestone. There is no evidence to suggest that the Hazel sandstone ever overlay the Carrizo Mountain formation. Even if it did it is highly improbable that it would have been carried forward on the flat type of thrust indicated. Therefore, it does not seem logical to restore the purely hypothetical surface that would be necessary if we continue to call the Van Horn uplift the highest structure in Texas.

More than 5,000 feet of Paleozoic beds are present on the west flank of the Franklin Mountains.[5] There is every indication that, until recently, these beds extended across what is now the crest of the range. All of these beds are older than any of the Permian beds exposed in the Guadalupe Mountains. A structure map on the restored topmost horizon of these post-Cambrian beds in the Franklins would show an uplift thousands of feet higher than that in the Guadalupes or on the Van Horn uplift. We are limited to the Permian as the highest of the younger formations on which to make comparisons, because it cannot be shown that the Cretaceous or any younger series of rocks ever completely covered any of the higher uplifts in this part of trans-Pecos Texas. But on the basis of the pre-Cambrian and the Permian the Franklin Mountain uplift is the highest structure in Texas.

[4] P. B. King, *op. cit.* (1940).

[5] L. A. Nelson, "Paleozoic Stratigraphy of the Franklin Mountains, West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), pp. 157–72.

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REVIEWS AND NEW PUBLICATIONS

*Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

MINERALS IN WORLD AFFAIRS, BY T. S. LOVERING

REVIEW BY JOHN L. FERGUSON[1]
Tulsa, Oklahoma

Minerals in World Affairs, by T. S. Lovering. Prentice-Hall Geology Series (1943). 394+ix pp., including preface, table of contents, list of illustrations, appendix, and index. Prentice-Hall, Inc., New York, N. Y. Price, $5.35.

"The concentrated value of . . . minerals has stimulated exploration, their exploitation has led to commerce and power, their exhaustion to national decline and poverty." This historically accurate statement of the importance of minerals in world affairs furnishes the foundation for Dr. Lovering's discussion of 16 important minerals. These are divided into three groups: the mineral fuels comprising coal and petroleum, the ferrous and ferro-alloy metals including iron and steel, manganese, chromium, nickel, tungsten, molybdenum and vanadium; the nonferrous industrial metals, copper, aluminum, lead, zinc, tin, mercury and antimony.

A chapter is devoted to each of these minerals which is discussed briefly under the headings of uses, technology, economics, geology, distribution of important occurrences, production and consumption, political and commercial control, and influence on national policies. Small-scale maps accompany each chapter showing the world occurrence of the mineral under discussion, and a short bibliography closes each chapter.

The outstanding part of the book is the introductory discussion of the economics, history, and geology of minerals and their influence on national power in accordance with the quotation at the beginning of this review. Dr. Lovering devotes one-third of the book to this careful analysis of the rôle of minerals in the past in order that their present status in world affairs may be more readily ascertained.

A fine balance is maintained in the discussion of the various minerals, with petroleum and iron and steel rightly receiving somewhat greater prominence. The information is condensed, and possibly too much coverage has been attempted in the small space allotted to each mineral.

The book is well printed in large type on heavy coated paper, and the sparse illustrations are well selected. The occurrence maps are somewhat disappointing due to their symbolic representation of mineral localities throughout the world. This is especially noticeable for petroleum which is shown on the same maps as coal, and suffers unnecessarily by comparison.

Minerals in World Affairs makes a concise handbook of the salient facts regarding sixteen important minerals, places them squarely in world affairs, and should serve as a useful text for courses in economic geology.

[1] Amerada Petroleum Corporation. Manuscript received, February 17, 1944.

THE PHYSICS OF BLOWN SAND AND DESERT DUNES, BY R. A. BAGNOLD

REVIEW BY PARRY REICHE[1]
Albuquerque, New Mexico

The Physics of Blown Sand and Desert Dunes, by R. A. Bagnold. xx+265 pp., 16 photographic plates, 84 text diagrams. Wm. Morrow and Company (1943). Price, $5.00.

This is an important book. It summarizes and extends material presented in a series of papers by Major Bagnold (now Lieutenant Colonel) appearing in British journals in the late thirties. Based on many years experience in the Libyan Desert and on painstaking wind-tunnel experiments, it furnishes a physical explanation of the movement of sand under the wind. It is written with admirable clarity and economy of words, and is further marked by an essential continuity reminiscent of a mathematics text. Hence, it is not a book which can be readily skimmed and sampled. Notwithstanding a satisfying rigor of treatment, the book does not presuppose any mathematical skills in the reader, although familiarity with the significance of common symbols through the differential calculus is assumed.

It is an interesting confirmation of the contention that even the "purest" of scientific investigations inevitably finds practical application and that Bagnold's labors were of great value in planning and successfully executing maneuvers during the North African campaigns, in which the author took an active part. His understanding of the causes and origin of "firm" and "dry quicksand" areas, which are identical in appearance, aided in their recognition and thus facilitated motor transport. Presumably, also, his data on the localization of available ground water in the dunes were of direct value.

On the purely scientific side, *The Physics of Blown Sand and Desert Dunes* opens promising vistas in the study of climatic changes; by implication it advances one and possibly two new quantitative criteria for the recognition of aeolian deposits; it suggests a rapid means for the meteorological survey of large areas now scarcely known, and, by analogy, it may aid in an understanding of the problems of water transport of débris. The latter consideration, indeed, is specifically dealt with in illuminating passages throughout the book. The recognition that the flanks of a graph of grain-size against weight-frequency per unit of log-difference in seive openings, for aeolian sands, constitute two independent power functions, and the uses to which the data thus afforded may be put in statistical sedimentology are worthy of special mention.

Geologists at all seriously concerned with problems of sedimentology, paleoclimatology (especially that of the early Recent), or the geomorphology of arid regions will find that the book fully repays any study that they may give it.

[1] Department of geology, University of New Mexico. Review received, March 3, 1944.

RECENT PUBLICATIONS

CALIFORNIA

*"Miocene Radiolarian Faunas from Southern California," by Arthur S. Campbell and Bruce L. Clark. *Geol. Soc. America Spec. Paper 51* (New York, February 14, 1944). 76 pp., 7 pls.

*"Antelope Hills Oil Field," by W. T. Woodward. *California Oil Fields*, Vol. 28, No. 2 (San Francisco, July–December, 1942). (Received, March, 1944), pp. 7–11; 3 pls.

"Imperial Carbon Dioxide Gas Field," by Stephen H. Rook and George C. Williams. *Ibid.*, pp. 13–33; 5 figs., 4 pls.

CANADA

*"Mackenzie River Basin Best Opportunity for Oil in Canada," by G. S. Hume. *Oil Weekly*, Vol. 113, No. 2 (Houston, March 13, 1944), pp. 18–26; 2 maps.

GENERAL

*"Fish Remains from the Middle Devonian Bone Beds of the Cincinnati Arch Region," by John W. Wells. *Paleontographica Americana, Illustrated Contributions to the Invertebrate Paleontology of America*, Vol. 3, No. 16 (Palaeontological Research Institution, Ithaca, New York, February 26, 1944). 62 pp., 8 pls., 9 figs. Paper, 9.5×12.5 inches.

*"Study and Revision of Archimedes (Hall)," by G. E. Condra and M. K. Elias. *Geol. Soc. America Spec. Paper 53* (New York, February 29, 1944). 243 pp., 41 pls., 83 tables, 6 figs.

ILLINOIS

*"Undiscovered Oil Reserves in Illinois," by M. M. Leighton. *Oil Weekly*, Vol. 113, No. 2 (Houston, March 13, 1944), pp. 30–33; 1 fig.

KANSAS

*"Ground Water in the Oil-Field Area of Ellis and Russell Counties, Kansas," by John C. Frye and James J. Brazil. *Kansas Geol. Survey Bull. 50* (Lawrence, December, 1943). 104 pp., 14 tables, 9 figs., 2 pls.

*"The Stratigraphy and Structural Development of the Forest City Basin in Kansas," by Wallace Lee. *Ibid., Bull. 51* (December, 1943). 142 pp., 22 figs., 2 tables.

MEXICO

*"Geology and Paleontology of the Permian Area Northwest of Las Delicias, Southwestern Coahuila, Mexico," by Robert E. King, Carl O. Dunbar, Preston E. Cloud, Jr., and A. K. Miller. *Geol. Soc. America Spec. Paper 52* (New York, February 26, 1944). 172 pp., 45 pls., 29 figs.

MISSISSIPPI

*"Geology and Ground-Water Supply at Camp McCain," by Glen Francis Brown and Robert Wynn Adams, in coöperation with the U. S. Geological Survey. *Mississippi Geol. Survey Bull. 55* (University, 1943). 116 pp., 14 tables, 11 pls.

*"Geology and Ground Water Supply at Camp Van Dorn," by Glen Francis Brown and William Franklin Guyton, in coöperation with the U. S. Geological Survey, *Ibid., Bull. 56* (1943). 68 pp., 13 pls., 9 tables.

PENNSYLVANIA

*"Middle Ordovician of Central Pennsylvania," by G. Marshall Kay. *Jour. Geol.*, Vol. 52, No. 1 (Chicago, Illinois, January, 1944), pp. 1–23; 10 figs., 6 tables.

"Oil and Gas Geology of the Oil City Quadrangle," by Parke A. Dickey, R. E. Sherrill, and L. S. Matteson. *Pennsylvania Topog. and Geol. Survey M 25* (Harrisburg, March, 1944). Division of Documents, 10th and Market Streets, Harrisburg. Price, $1.00.

TEXAS

"Oil Possibilities of Sierra Diablo, Hudspeth and Culberson Counties, Texas." *U. S. Geol. Survey Prelim. Map 2*, Oil and Gas Investig. Ser. (March, 1944). Scale, 1 mile to the inch. Includes structure sections. May be purchased from the Director, U. S. Geol. Survey, Washington, D. C. Price, $0.40.

*"Permian Basin Pays Are Many and Deep," by Paul F. Osborne. *World Petroleum*, Vol. 15, No. 3 (New York, March, 1944), pp. 44-49; 11 illus.

WYOMING

"Structure Contour Map of the Big Horn Basin, Wyoming and Montana," by David A. Andrews, William G. Pierce, and Jewell J. Kirby. *U. S. Geol. Survey Prelim. Map 3*, Oil and Gas Investig. Ser. (March, 1944). Scale, 3 miles to the inch. 38×48 inches. Contour interval, 200 feet. May be purchased from the Director, U. S. Geol. Survey, Washington, D. C. Price, $0.40.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

Journal of Paleontology (Tulsa, Oklahoma), Vol. 18, No. 2 (March, 1944).

"Fossil Corals of the Genus *Turbinolia* from the Gulf Coast," by Edward Monsour.

"Revision of *Campophyllum* in North America," by William H. Easton.

"The Composition of Conodonts," by Samuel Ellison.

"Permian and Pennsylvanian Fresh-Water Ostracodes," by Harold W. Scott.

"Occurrence of the Russian Genus Rhombotrypella in Utah," by G. E. Condra and M. K. Elias.

"New Ostracoda from Subsurface Middle Tertiary Strata of Texas," by Morton B. Stephenson.

"Muscle-Scar Patterns on Some Upper Paleozoic Ostracodes," by Harold W. Scott.

"New West American Species of the Foraminiferal Genus *Elphidium*," by David Nicol.

"Foraminifera from the Tumey Formation, Fresno County, California," by Joseph A. Cushman and Russell R. Simonson.

"Some Larger Foraminifera from the Lower Cretaceous of Texas," by R. Wright Barker.

"Machine for Serial Sectioning of Fossils," by F. Russell Olsen and Frank C. Whitmore, Jr.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 4 (APRIL, 1944), PP. 569-570

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Warren LeRoy Constant, Houston, Tex.
M. E. Halsted, James W. Kisling, Jr., Howard R. Born
John Finley Doyle, Jr., Dallas, Tex.
F. H. Lahee, P. W. McFarland, E. W. Hard
Jessie Kelsey Liddell, San Antonio, Tex.
Leo R. Newfarmer, V. E. Monnett, Charles E. Decker
Erwin Ralph Scott, Kilgore, Tex.
M. L. Kerlin, A. C. Wright, G. D. Thomas
Edward James Smith, Jr., Houston, Tex.
G. A. Berg, H. L. Burchfiel, Leonard W. Orynski

FOR ASSOCIATE MEMBERSHIP

Albert Lorenzo Ballou, Tulsa, Okla.
Charles E. Decker, V. E. Monnett, J. W. Hoover
Henry Waring Bradley, Dallas, Tex.
E. C. Reagor, W. R. Ransone, C. V. A. Pittman
Tennant Julian Brooks, Bakersfield, Calif.
Glenn C. Ferguson, Stanley G. Wissler, Rollin Eckis
Andrew Max Current, Shreveport, La.
Phil K. Cochran, Robert W. Beck, William S. Hoffmeister
Charles Frederick Haas, Corpus Christi, Tex.
C. C. Miller, L. B. Herring, E. A. Taegel
Wayne Franklin Meents, Urbana, Ill.
M. M. Leighton, Alfred H. Bell, L. E. Workman
Clarence Scott Mumford, Tulsa, Okla.
R. E. Shutt, Sherwood Buckstaff, Hilton L. Rickard
John Marchbank Parker, Manhattan, Kan.
Theodore A. Link, John A. Allan, Louis Desjardins
Eugene Stanley Richardson, Jr., Philadelphia, Pa.
Paul D. Krynine, John R. Fanshawe, W. T. Thom, Jr.
Lucille Evelyn Treybig, Houston, Tex.
John S. Cruse, Jr., James S. Kirkendall, Morris E. Halsted

FOR TRANSFER TO ACTIVE MEMBERSHIP

Robert Gilmore Anderson, Abilene, Tex.
V. C. Perini, Jr., Riley G. Maxwell, K. B. Nowels
George J. Gaenslen, Midland, Tex.
W. D. Anderson, J. W. Kisling, Jr., Neal J. Bingman

Ralph H. Lang, Pittsburgh, Pa.
J. B. Lovejoy, C. D. Cordry, B. E. Thompson
Barney Cliffton McCasland, Jr., Shreveport, La.
R. L. McLaren, J. D. Aimer, E. L. Caster
Grover E. Murray, Jr., Jackson, Miss.
S. A. Thompson, Henry V. Howe, L. R. McFarland
Joseph Bernard Petta, Fort Worth, Tex.
Joseph H. Markley, Jr., D. G. Stookey, H. H. Bradfield
Milton William Pullen, Jr., Urbana, Ill.
M. M. Leighton, A. H. Bell, L. E. Workman
Israel Gregory Sohn, Spokane, Wash.
John B. Reeside, Jr., Lloyd G. Henbest, Ralph W. Imlay
Ivan F. Wilson, Washington, D. C.
George G. Louderback, Lester C. Uren, Bruce L. Clark

ADDITIONAL MEMBERSHIP APPLICATIONS APPROVED

FOR ACTIVE MEMBERSHIP

Platte T. Amstutz, Jr., Cleveland, Ohio
John P. Smoots, Eugene A. Stephenson, Edward A. Koester
Godfrey Charles Beckman, Rio Vista, Calif.
George M. Cunningham, George L. Knox, Stephen H. Gester
Robert P. Bryson, Washington, D. C.
Lloyd W. Stephenson, Carle H. Dane, Hugh D. Miser
Stuart Edward Buckley, Houston, Tex.
L. T. Barrow, Morgan J. Davis, John R. Suman
Walter William Butcher, Maracaibo, Venezuela, S.A.
A. J. Freie, John G. Douglas, J. H. Sawyer
Albert A. Carrey, Long Beach, Calif.
C. M. Gardiner, R. W. Sherman, Richard R. Crandall
Clyde Grant Dickinson, San Antonio, Tex.
H. R. Hostetter, Howard H. Lester, P. S. Morey
Hodge Mobray Falkenhagen, Houston, Tex.
D. F. Broussard, Joseph L. Adler, George S. Buchanan
Katherine Fielding Greacen, Midland, Tex.
John R. Ball, Albert O. Hayes, Aldred S. Warthin, Jr.
Claude Wendell Horton, Cambridge, Mass.
F. Goldstone, W. Hafner, W. S. Adkins
Herbert Moore Houghton, Houston, Tex.
A. L. Ladner, J. B. Ferguson, Andrew Gilmour
Floyd G. Kerns, Oklahoma City, Okla.
Hubert E. Bale, Richard W. Camp, J. T. Richards
Ralph LeRoy Miller, Washington, D. C.
Arthur A. Baker, Hugh D. Miser, William G. Pierce
Berlen C. Moneymaker, Knoxville, Tenn.
Paul D. Krynine, Nicholas A. Rose, L. C. Glenn
Robert Emmett Morrison, Odessa, Tex.
Philip D. Larson, V. E. Monnett, Richard E. Gile

(Continued on page 575)

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 4 (APRIL, 1944), PP. 571-576

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

DOUGLAS W. JOHNSON, of the geology department of Columbia University, New York City, died at the age of 65 years, February 24, at Sebring, Florida.

E. J. DANIEL, of St. Ives, Cornwall, England, is in the Indian Army.

HAROLD ENLOWS, recently teaching geology at Tulsa University, has completed training in meteorology at Annapolis, Maryland.

ROBERT H. DOTT, director of the Oklahoma Geological Survey, has been elected vice-president of the Association of American State Geologists.

CHARLES J. DEEGAN, recently with the Petroleum Administration for War, has joined the editorial staff of the *Oil and Gas Journal* at Tulsa, to direct the exploration and drilling department.

RICHARD T. LYONS has been elected vice-president of the Tide Water Associated Oil Company, Houston, Texas.

M. KING HUBBERT, of the Shell Oil Company, Inc., delivered a paper on "The Strength of the Earth," before the Houston Geological Society, March 2.

KARL L. WALTER talked on "Reconnaissance of Southern Chilean Patagonia," at the regular meeting of the Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, March 6.

J. C. MARTIN, JR., has resigned his position as geologist with The Texas Company and has joined the geological staff of Crown Central Petroleum Corporation, Houston, Texas.

E. H. RAINWATER, stratigrapher, has been transferred by Shell Oil Company, Inc., from Houston, Texas, to Tallahassee, Florida.

PAUL T. WALTON has left The Texas Company and is now division geologist of the Rocky Mountain area for the Pacific Western Oil Corporation, George F. Getty, Inc., and Skelly Oil Interests. His office is at 405 Consolidated Royalty Building, Casper, Wyoming.

J. W. GWINN is with the Standard Oil Company of Cuba, Apartado 1303, Habana, Cuba.

JOHN F. BARRETT, formerly with The California Company at New Orleans, Louisiana, has joined the Barnsdall Oil Company, Houston, Texas.

LIEUTENANT WARREN D. SORRELLS is in the Office of the Quartermaster General, Fuels and Lubricants Division, Washington, D. C. He was formerly with the Standard Oil Company of Venezuela at Caripito.

MAJOR BENJAMIN M. SHAUB is in the Ordnance Department, U. S. Army. He has been on leave from Smith College since March, 1941.

J. Q. ANDERSON, of The Texas Company, spoke on "Miocene Stratigraphy of the East Coalinga Oil Fields," before the San Joaquin Geological Society, Bakersfield, California, February 16.

ALEXANDER CLARK, formerly at Calgary, Alberta, Canada, may be addressed at 1008 West 6th Street, Ventura, California. He is with the Shell Oil Company, Inc.

The Southeastern Geological Society was organized at Tallahassee, Florida, February 18, with the following officers: president, HERMAN GUNTER, State geologist; vice-president, ROBERT B. CAMPBELL, consulting geologist; secretary-treasurer, R. M. SWESNIK, Sun Oil Company, Box 186, Tallahassee. There are 28 members.

JOHN L. P. CAMPBELL, of the Lane-Wells Company, Houston, spoke before the South Texas Geological Society at San Antonio, March 6, on "Radioactivity Well Logging."

ARTHUR W. NAUSS has moved from Edmonton, Alberta, Canada, to Talara, Peru. He is with the International Petroleum Company.

E. H. VALLAT, formerly with the Continental Oil Company, has joined the Ohio Oil Company, 437 South Hill Street, Los Angeles, California.

J. J. BRYAN, formerly with the Tide Water Associated Oil Company, is now geologist for the Union Oil Company of California, Bakersfield, California.

ALFRED CUMMING is situated at Bixby, Oklahoma, Route 1, Box 11A.

LIEUTENANT-COLONEL O. W. URBOM is Post Engineer at Camp Barkeley, Texas.

JOE CANNON, of the Petroleum Administration for War, has moved from Tulsa, Oklahoma, to 624 South Michigan Avenue, Chicago, Illinois.

HARRY H. SISSON, formerly party chief with the General Geophysical Company, Houston, is employed by the Gulf Oil Corporation, geophysical department, Fort Worth. His address is Box 1150, Midland, Texas.

QUENTIN D. SINGEWALD is on leave of absence from the University of Rochester, as geologist on the staff of the U. S. Geological Survey, serving as head of a party engaged in work for the Foreign Economic Administration in Colombia, South America. His present address is c/o American Embassy, Bogota, Colombia.

A. L. SOLLIDAY, of the Stanolind Oil and Gas Company, Tulsa, Oklahoma, has been made vice-president in charge of operations. He was formerly manager of explorations.

STUART ST. CLAIR is chief of the Smelter Section of the Mining Division of the War Production Board, Washington, D. C. He had an illustrated article on the East Indies in the September issue of the *National Geographic Magazine*. His permanent address is Hudson View Gardens, 183d Street and Pinehurst Avenue, New York City.

C. B. SWARTZ, of the Carter Oil Company, has been transferred from district geologist of Arkansas to district geologist of Louisiana and Arkansas, with headquarters at Shreveport, Louisiana.

The A.I.M.E. Petroleum Division will hold its spring meeting at the Rice Hotel, Houston, Texas, May 8, 9, and 10.

HENRY ANDREW BUEHLER, geologist and director of the Missouri Bureau of Geology and Mines, at Rolla, died March 14, at the age of 67 years. He had been with the State Survey 43 years.

CHARLES S. LAVINGTON, after about 20 years with the Continental Oil Company, has resigned to go into business for himself. His address is 1950 Holly Street, Denver, Colorado.

Roy G. Mead, Jr., who was formerly employed as geologist for the Mohawk Petroleum Company, recently completed the officers' training course in the Marine Corps at Quantico, Virginia, and is now a Second Lieutenant, Intelligence Officer, stationed somewhere in the South Pacific.

Richard V. Hughes has resigned his position as chief of the development unit of the reservoir engineering section of the Production Division, Petroleum Administration for War, at Washington, to accept on March 1, the position of director of research for the Penn Grade Crude Oil Association. The Penn Grade area includes all producing areas in Pennsylvania, New York, Southeastern Ohio, and West Virginia. Headquarters will be at Bradford, Pennsylvania.

The South Texas Geological Society at its annual meeting held on March 6 in the Cascade Room of the St. Anthony Hotel, San Antonio, Texas, elected the following officers for the year 1944: president, Robert N. Kolm, Atlantic Refining Company; vice-president, Donald O. Chapell, Transwestern Oil Company; secretary-treasurer, Robert D. Mebane, Saltmount Oil Company; executive committee member, E. Floyd Miller, A. G. Oliphant Oil Company. The Society, which is an official Section of the Association, completed a successful year with regular monthly meetings held on the first Monday evening of each month at which a special speaker was the main feature. Six of these speakers were those sponsored by the A.A.P.G. distinguished lecture program and the remaining guest speakers discussed various geological or allied subjects. In addition, regular weekly Monday luncheons have been held at the Milam Cafeteria with numerous short talks on current geological problems, new oil or gas fields, or other popular subjects. Visiting geologists and friends are welcome at the Society's meetings.

Robert H. Dott, director of the Oklahoma Geological Survey, Norman, spoke on "Current Operations of the Oklahoma Geological Survey," at the bi-monthly luncheon of the Oklahoma City Geological Society, March 16.

W. V. Howard, consulting geologist, presented a paper, "The Basis on Which Our Science Rests," before the Tulsa Geological Society, March 6. A kodachrome film, "Winter Surveying in Manitoba," was shown through the courtesy of the Surveys Branch of the Department of Mines and Natural Resources of Manitoba, Canada.

Marshall Kay, professor of geology at Columbia University, appeared before the following geological societies in March under the auspices of the distinguished lecture committee. He presented a well illustrated lecture based on his years of study of the Appalachian and other geosynclines, entitled "Geosynclines in Continental Development."

March 6 Engineers Society of Western Pennsylvania at Pittsburgh
7 Indiana-Kentucky Geological Society at Evansville
8 Illinois Geological Society at Mattoon
9 Mississippi Geological Society at Jackson
10 Shreveport Geological Society at Shreveport
11 East Texas Geological Society at Tyler
13 South Louisiana Geological Society at Lake Charles
14 Houston Geological Society at Houston
16 North Texas Geological Society at Wichita Falls
17 Fort Worth Geological Society at Fort Worth
18 West Texas Geological Society at Midland
24 Oklahoma City and Shawnee Geological Societies at Shawnee
27 Tulsa Geological Society at Tulsa
28 Tulsa Geological Society at Bartlesville
29 Kansas Geological Society at Wichita

In the course of his trip Dr. Kay attended the Dallas convention of the A.A.P.G. as the guest of the affiliated societies.

EDWARD V. WINTERER, of the Superior Oil Company, Los Angeles, California, died on March 14, at the age of 46 years.

JOSEPH A. TAFF, of Palo Alto, California, honorary member of the Association, died in March, at the age of 82 years. He was chief geologist of the Associated Oil Company from 1926 to 1929, and a consulting geologist since 1929.

W. A. WALDSCHMIDT is in the employ of Case, Pomeroy and Company, Inc., Box 1888, Midland, Texas.

A. E. PETTIT, recently with the Hamilton Gas Corporation at Charleston, West Virginia, is in the employ of the Magnolia Petroleum Company, Mt. Vernon, Illinois.

V. E. AUTRY, formerly with the Fain-McGaha Oil Corporation, is associated with MELVIN M. GARRETT, consulting geologist, Republic Bank Building, Dallas, Texas.

K. F. HUFF has left Edmonton, Alberta, Canada, to join the International Petroleum Company, Ltd., at Guayaquil, Ecuador, S.A.

MIGUEL DE LAVEAGA is working for the Capital Company, Los Angeles, California.

MERRITT B. SMITH, formerly with E. A. Parkford, is employed by DWIGHT G. VEDDER, as geologist.

DOUGLAS FYFE has been for the past two years chief geologist in charge of oil exploration in Eastern Peru for the Peruvian Government. With him as assistants have been NORMAN D. NEWELL and BERNARD DUMMEL.

Major BENJAMIN F. HAKE, who was district geologist for the Gulf Oil Corporation in Michigan-Illinois-Indiana area, is now assistant chief of the Planning Branch, Fuels and Lubricants Division, Office of The Quartermaster General in Washington. Major RAYMOND C. MOORE, formerly State geologist of Kansas, is chief of the Development and Rehabilitation Section, in the same office. Other Association members included in the Planning Branch are 1st. Lt. DON D. MONTGOMERY of El Dorado, Arkansas, and 1st Lt. WARREN D. SORRELLS of Abilene, Texas, who spent several years in Venezuela. The Planning Branch has responsibility for recommendations of petroleum plans and policies of the U. S. Army (except aircraft).

JOHN R. FANSHAWE has resigned as director of Reserves with the Petroleum Administration for War and is now working for the General Petroleum Corporation of California as a field geologist stationed at Billings, Montana.

RICHARD A. GEYER, recently with the Bureau of Ordnance, Navy Department, has accepted a position with the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

J. W. WADDLE, of the McKamie Gas Cleaning Company, Magnolia, Arkansas, explained the operation of the plant and facilities used to separate the products from a sour gas-condensate reservoir, at the regular meeting of the Shreveport Geological Society, Shreveport, Louisiana, March 27.

The Houston Geological Society, Houston, Texas, recently had the following on the regular program. H. N. FISK, of Louisiana State University, Baton Rouge, talked on "Geological History of the Alluvial Valley of the Lower Mississippi River," April 6. J. EMERY ADAMS, Standard Oil Company of Texas, Carlsbad, New Mexico, talked on "Depth Control of Sedimentation in the Permian Basin," April 13.

KENNETH L. GOW, of the Superior Oil Company, talked on "Geology and Oil Fields of the Illinois Basin with Remarks on Electrical Logging," at the regular meeting of the Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, April 3.

J. J. ZORICHAK is now secretary-treasurer of the Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, succeeding A. W. WEEKS, of the Petroleum Administration for War, who has returned to the Philadelphia office of P.A.W.

ADDITIONAL MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

(Continued from page 570)

FOR ACTIVE MEMBERSHIP

Decatur O'Brien, Woodville, Tex.
D. P. Carlton, O. D. Brooks, F. F. Campbell
Charles Wesley Porter, Bakersfield, Calif.
R. L. Hewitt, W. D. Cortright, J. J. Bryan
Lucien A. Puzin, Wichita Falls, Tex.
Dan D. Heninger, Donald Kelly, P. M. Martin
Henry Gustav Raish, Midland, Tex.
Robert I. Dickey, Sam C. Giesey, W. D. Henderson
Cletus Daniel Roemer, Tulsa, Okla.
G. S. Lambert, R. E. Shutt, Sherwood Buckstaff
Morris Grady Spencer, Dallas, Tex.
Barney Fisher, J. C. Karcher, Cecil H. Green
Robert Charles Spivey, Midland, Tex.
Bruce H. Harlton, R. V. Hollingsworth, E. Russell Lloyd

FOR ASSOCIATE MEMBERSHIP

Allen Francis Agnew, Platteville, Wis.
F. W. DeWolf, Harold R. Wanless, Charles H. Behre, Jr.
Robert Edwin Anderson, Los Angeles, Calif.
Edgar W. Owen, J. H. Kinser, Ian Campbell
Leslie Winston Dorbandt, Midland, Tex.
Niles B. Winter, Lee B. Park, Dana M. Secor
Ruth Mary Dudley, Tulsa, Okla.
Norman D. Newell, W. H. Twenhofel, Raymond C. Moore
Samuel Thomas Fee, Providence, R. I.
L. W. LeRoy, J. Harlan Johnson, F. M. Van Tuyl
Hamlin Garland Fox, Tyler, Tex.
E. B. Branson, M. G. Mehl, L. K. Lancaster
Eldon Woodrow Langford, Seminole, Tex.
L. C. Snider, Hal P. Bybee, C. O. Fletcher
Lamar McLennan, Jr., Midland, Tex.
Robert I. Dickey, O. R. Champion, Laurence Lees
James Howard Morris, Quitman, Miss.
Watson H. Monroe, Garrett A. Muilenburg, Samuel P. Ellison, Jr.
Waynard George Olson, Denver, Colo.
Charles S. Lavington, A. E. Brainerd, Horace D. Thomas

Luther Clinton Powell, New Orleans, La.
G. W. Gulmon, J. W. Hoover, Arthur McFarlan
E. Harold Rader, Los Angeles, Calif.
W. S. W. Kew, R. G. Reese, Herschel L. Driver
Lois Jane Schulz, Midland, Tex.
F. W. DeWolf, W. D. Henderson, H. R. Wanless
Mary Elizabeth Sheldon, San Antonio, Tex.
Hal P. Bybee, Fred M. Bullard, Charles H. Row
Richard Cortez Shelton, Little Rock, Ark.
A. O. Woodford, R. Ten Eyck, R. M. Barnes
Harry Allison Tourtelot, University, Miss.
Watson H. Monroe, E. F. Schramm, A. L. Lugn
Morris Barksdal White, Oklahoma City, Okla.
Frank Buttram, Harold D. Jenkins, I. Curtis Hicks
Edwin Philp Williams, Calgary, Alta., Canada
T. B. Williams, Leslie M. Clark, F. L. Fournier
James Lee Wilson, Billings, Mont.
W. A. Bramlette, D. L. Blackstone, Jr., O. A. Seager

FOR TRANSFER TO ACTIVE MEMBERSHIP

Richard S. Anderson, Fort Worth, Tex.
O. C. Harper, H. A. Hemphill, M. T. Hartwell
William L. Broadhurst, Austin, Tex.
F. B. Plummer, Joseph W. Lang, W. O. George
James Russell Reeves, Dallas, Tex.
J. David Hedley, J. J. Travis, E. A. Markley
Felix Anthony Runion, Houston, Tex.
H. J. McLellan, Morgan J. Davis, Perry Olcott
Rayman Sturdevant, Sacramento, Calif.
Frank W. Bell, M. G. Edwards, Arne Junger
Charles Henry Summerson, Albuquerque, N. Mex.
Harold R. Wanless, Harold W. Scott, F. W. DeWolf

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
DENVER, COLORADO

President - - - - - - - - - Ben H. Parker
Colorado School of Mines, and Frontier Refining Company
1st Vice-President - - - - - - Dart Wantland
Colorado School of Mines
2nd Vice-President - - - - Wm. B. Kramer
U. S. Geological Survey
Secretary-Treasurer - - - - - - J. J. Zorichak
Petroleum Administration for War
First National Bank Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - Darsie A. Green
The Pure Oil Company, Box 311, Olney

Vice-President - - - - - - - Otto E. Brown
Gulf Oil Corporation, Mattoon

Secretary-Treasurer - - - - - Fred H. Moore
Magnolia Petroleum Corp., Box 535, Mt. Vernon

Meetings will be announced.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY
EVANSVILLE, INDIANA

President - - - - - - - - George R. Wesley
Skelly Oil Co.

Vice-President - - - - - - - Robert F. Eberle
The Superior Oil Company

Secretary-Treasurer - - - - Hillard W. Bodkin
The Superior Oil Company

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - - - Leo R. Fortier
Alpine Oil and Royalty Co.
Vice-President - - - - - - - Virgil B. Cole
Gulf Oil Corporation
Secretary-Treasurer - - - - Delbert J. Costa
Superior Oil Co. of California
417 First Natl. Bank Bldg.
Manager of Well Log Bureau - Harvel E. White

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Bldg.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - - - - - H. C. Petersen
Freeport Sulphur Co., American Bank Bldg.
Vice-President and Program Chm. - - - - - - - - - - - - - - - - Dean F. Metts
Humble Oil and Refining Company
1405 Canal Bldg.
Secretary-Treasurer - - - - - B. E. Bremer
The Texas Company, P.O. Box 252

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - - - W. H. Spears
Union Producing Company, Drawer 1407
Vice-President - - - - - - - T. H. Philpott
Carter Oil Company, Drawer 1739
Secretary-Treasurer - - - - - - E. P. Ogier
c/o W. C. Spooner, Box 1195

Meets the first Tuesday of every month, September to May, inclusive, 7:30 P.M., Criminal Courts Room, Caddo Parish Court House. Special meetings and dinner meetings by announcement.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - - C. B. Roach
Shell Oil Company, Inc., Box 136
Vice-President - - - - - - - P. S. Shoeneck
Atlantic Refining Company
Secretary - - - - - - - - - Ben F. Morgan
Stanolind Oil and Gas Company
Treasurer - - - - - - - Robert N. Watson
Atlantic Refining Company, Box 895

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - Edward J. Baltrusaitis
Gulf Refining Company, Box 811, Saginaw
Vice-President - - - - Raymond S. Hunt
Consulting, 405 S. Main, Mt. Pleasant
Secretary-Treasurer - - - - Thomas S. Knapp
The Chartiers Oil Co., Box 227, Mt. Pleasant
Business Manager - - - - - - Lee S. Miller
Michigan Geological Survey,
Capitol Savings and Loan Bldg., Lansing

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - - K. K. Spooner
The Atlantic Refining Company, Box 2407

Vice-President - - - - - Lyman C. Dennis
Pure Oil Company, Box 1141

Secretary-Treasurer - - - - - C. L. Morgan
Consulting, Edwards Hotel

Meetings: First and third Wednesdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - - John Marshall
The Texas Company, Box 539

Vice-President - - - - - - Frank Neighbor
Sinclair Prairie Oil Company

Secretary-Treasurer - - - - - - S. L. Rose
618 Simpson Building

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - - I. Curtis Hicks
Phillips Petroleum Company
1211 First National Building

Vice-President - - - - - - E. G. Dahlgren
Interstate Oil Compact Commission
State Capitol

Secretary-Treasurer - - - - Theodore G. Glass
Sinclair Prairie Oil Company
703 Colcord Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder Luncheons: Every Thursday, at 12:00 noon. Y.W.C.A. Cafeteria.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - - Edwin A. Dawson
1829 N. Broadway

Vice-President - - - - - - - Roy McAninch
Stanolind Oil and Gas Company, Box 1099

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - Robert E. Garrett
Consulting Geologist, 301 Beacon Building

1st Vice-President - - - - - - - J. V. Howell
912 Philtower

2nd Vice-President - - - - - - - Jerry E. Upp
Amerada Petroleum Corporation

Secretary-Treasurer - - - - - - James A. Price
W. C. McBride, Inc., 625 Wright Bldg.

Editor - - - - - - - - - - - Roy L. Ginter
Ginter Laboratory

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Bradford Hotel.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

President - - - - - - - - - Frith C. Owens
Consulting, Nixon Building

Vice-President - - - - - - - Edwin A. Taegel
The Chicago Corporation

Secretary-Treasurer - - - John Bruce Scrafford
Consulting, Driscoll Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

DALLAS PETROLEUM GEOLOGISTS
DALLAS, TEXAS

President - - - - - - - - Joseph M. Wilson
Continental Building

Vice-President - - - - - - - Henry C. Cortes
Magnolia Petroleum Company

Secretary-Treasurer - - - - H. C. Vanderpool
Seaboard Oil Company

Executive Committee - - - - Cecil H. Green
Geophysical Service, Inc.

Meetings: Regular luncheons, first Monday of each month, 12:00 noon, Petroleum Club, Adolphus Hotel. Special night meetings by announcement.

TEXAS

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - G. J. Loetterle
Shell Oil Company, Inc., Box 2037
Vice-President - - - - - - - B. W. Allen
Gulf Oil Corporation
Secretary-Treasurer - - - - - L. L. Harden
Sinclair Prairie Oil Company, Box 1100
Executive Committee - - - - J. H. McGuirt
Magnolia Petroleum Company

Meetings: Monthly and by call.
Luncheons: Every Monday at 12:00 noon, Blackstone Hotel

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - Joseph H. Markley, Jr.
The Texas Company, Box 1720
Vice-President - - - - - - James L. Morris
The Pure Oil Company, Box 2107
Secretary-Treasurer - - - Spencer R. Normand
Independent Exploration Company
2210 Ft. Worth Natl. Bank Bldg.

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - - - Leslie Bowling
Union Oil Company of California
Vice-President - - - - - W. B. Milton, Jr.
Gulf Oil Corporation
Secretary - - - - - - - - - - W. B. Moore
Atlantic Refining Company, Box 1346
Treasurer - - - - - - - - - - G. J. Smith
Pan American Producing Company

Regular meeting held the first and third Thursdays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - Dan D. Heninger
The Ohio Oil Company, 615 Hamilton Bldg.
Vice-President - - - - - - Dolph E. Simic
Cities Service Oil Co.
Secretary-Treasurer - - - Carlos M. Ferguson
Magnolia Petroleum Co., 500 Waggoner Bldg.

Luncheons and evening programs will be announced.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO, TEXAS

President - - - - - - - Robert N. Kolm
Atlantic Refining Co., 1742 Milam Building
Vice-President - - - - - Donald O. Chapell
Transwestern Oil Co., 1600 Milam Building
Secretary-Treasurer - - - Robert D. Mebane
Saltmount Oil Co., 916 Milam Building

Meetings: Third Tuesday of each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - - Robert I. Dickey
Forest Development Corporation
Vice-President - - - - - George R. Gibson
Richfield Oil Corporation
Secretary-Treasurer - - - - - - Jane Ferrell
Magnolia Petroleum Company, Box 633

Meetings will be announced

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P. O. Box 2385

President - - - - - - - Douglas Rogers, Jr.
South Penn Natural Gas Company, Parkersburg
Vice-President - - - - - - Veleair C. Smith
Kanawha Valley Bank Building
Secretary-Treasurer - - - - - - A. E. Pettit
Hamilton Gas Corporation, Box 2387
Editor - - - - - - - - - H. J. Simmons, Jr.
Godfrey L. Cabot, Inc., Box 1473

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - William M. Rust, Jr.
Humble Oil & Refining Company, Houston, Texas
Vice-President - - - - - - Henry C. Cortes
Magnolia Petroleum Company, Dallas, Texas
Editor - - - - - - - - - - - - J. A. Sharpe
Stanolind Oil and Gas Company, Tulsa, Oklahoma
Secretary-Treasurer - - - - - W. H. Taylor
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